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Field Demonstration at Fort Jackson, SC

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Steven L. Larson, Jeffery L. Davis, W. Andy Martin, and Deborah R. Felt

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Gene Fabian and Greg Zynda

U.S. Army Aberdeen Test Center
400 Colleran Road
Aberdeen Proving Ground, MD 21005

Catherine C. Nestler

Applied Research Associates, Inc.
119 Monument Place
Vicksburg, MS 39180

Beth-Anee Johnson

ITAM-Shaw Environmental
Fort Jackson, SC 29207

Gregory O'Connor

U.S. Army RDECOM-ARDEC
Energetics, Warheads, and Environmental Technology Research Division
Building 355
Picatinny, NJ 07806-5000

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Abstract: The Department of Defense operates hundreds of hand grenade ranges (HGRs) for training purposes. Hand grenade training is a necessary function to maintain mission readiness for our nation's war fighters. Live fire training creates a potential source zone for munitions constituents such as metals and explosives. Fragmentation grenades, typically containing the high explosive composition B (60% RDX, 39%TNT) within a steel shell casing, constitute the majority of hand grenades used at fixed position ranges. Explosives have been detected in HGR soils at levels from the low parts per billion (µg/kg) up to percent levels. RDX has been detected in leachate waters below live fire HGRs and in surface waters leaving ranges. Two of the potential pathways for offsite migration of metals and explosives from HGR soil are transport in surface water and subsurface transport in leachate. Simple, innovative, and cost effective technologies are being developed which can break down munitions constituents quickly at the training sites and prevent residues from migrating to local surface water or groundwater supplies.

The application of hydrated lime to an HGR to provide a mechanism for both metals immobilization and explosives transformation was demonstrated at the Fort Jackson, SC HGRs. The results indicate that application of lime can reduce the munitions constituent migration by transforming energetic compounds by over 90%. In addition, the metals are stabilized in the soil, with reduction in the concentrations of iron and zinc leaving the range via surface water and leachate. This technology demonstrated that application of lime is a low-cost treatment that can be incorporated into range management operations and practices.

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Preface

The work reported herein was conducted at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS; Aberdeen Test Center (ATC), Aberdeen Proving Ground, MD; Picatinny Arsenal, Picatinny NJ; and Fort Jackson, SC Remagen Hand Grenade Range (HGR). Funding was provided by the Environmental Security Technology Certification Program (ESTCP) and the U.S. Army Environmental Quality Technology (EQT) program. The project was designated as ESTCP project ER-0216.

The work presented in this report was part of an effort to investigate the use of lime to immobilize metals and transform explosives on active HGRs. Dr. Steven L. Larson, Dr. Jeffery L. Davis, W. Andy Martin, and Deborah R. Felt of the ERDC-Environmental Laboratory (EL), Vicksburg, MS and Catherine C. Nestler of Applied Research Associates, Inc. (ARA), Vicksburg, MS prepared this report. Gene Fabian and Greg Zynda, ATC; Greg O'Connor (Energetics, Warheads, and Environmental Technology Research Division); and Beth-Anee Johnson of the ITAM-Shaw Environmental office at Fort Jackson, SC assisted them. The report was reviewed by Drs. S. Brasfield and A. Bednar of ERDC-EL. The authors gratefully acknowledge the technical assistance provided by Karl Konecny, Chris Griggs, and Jared Johnson (ERDC-EL); Milton Beverly (Environmental Research and Development, Inc.); Michelle Thompson (ARA); LeeAnn Riggs and Deborah Regan (SpecPro); Casey Trest (Mississippi State University); and Tarmiko Graham (Alcorn State University). We also wish to acknowledge the gracious participation of both the Remagen Hand Grenade Training Center Cadre and the Fort Jackson, SC range control personnel for their assistance and support throughout the duration of this project.

This study was conducted under the direct supervision of Dr. Victor F. Medina, Acting Chief, Environmental Engineering Branch; and Dr. Richard E. Price, Chief, Environmental Processes and Engineering Division; and under the general supervision of Dr. M. John Cullinane, EL Technical Director for Military Environmental Engineering and Science; and Dr. Beth Fleming, Director, EL.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
hectares	1.0 E+04	square meters
inches	0.0254	meters
inches	2.54	centimeters
microns	1.0 E-06	meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters

1 Introduction

Munitions on hand grenade ranges

Munitions-impacted soils on training ranges contain a mixture of contaminants (Pennington et al. 2001, 2002, 2006). Fragmentation grenades, which constitute the majority of hand grenades used at fixed position ranges, are typically composed of a steel shell and composition B explosive material. Studies performed on ranges in both the United States and Canada have shown that there is a large degree of variability in munition constituents, concentration, fragment size, and spatial distribution within individual ranges, as well as between different ranges (Pennington et al. 2006). Jenkins et al. (2001) described HGRs they studied as small in size (only a few hectares), poorly vegetated, with high explosive (HE) contamination concentrated in an area 15–35 m from the throwing pit, in a soil volume that is typically 20–60 m wide and with craters as much as 10–15 cm deep. Composition B is a mixture of 60% hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), 39% 2,4,6-trinitrotoluene (TNT), and 1% wax binder. The primary contaminant of concern is RDX because of its recalcitrant nature in the environment and its relatively low affinity for sorption to soil (Dontsova et al. 2006; Hatzinger et al. 2004). RDX has been found at concentrations ranging from <0.01–51 mg/kg at HGRs (Jenkins et al. 2006). Jenkins et al. (2006) assumed that low-order detonations (unexploded ordnance (UXO) and incompletely exploded ordnance) contributed most of the HE contamination on HGRs. Low-order detonations are discrete, point sources of munitions constituents with residue concentrations possible in the percent range in the immediate vicinity of the armament. Larson et al. (2007a) conducted a representative analysis of hand grenade residue from 30 hand grenades that performed as high order detonations. The authors (Larson et al. 2007a) reported an average residue load of 0.366 mg of RDX and high masses of small particle size iron (Fe) and zinc (Zn).

Metals on hand grenade ranges

Heavy metals on HGRs differ from those derived from mining or Industrial sources in that they are primarily metallic in form. The primary metals associated with hand grenade residues are iron and zinc. HGR metals are often less mobile, in general, compared to metals from other

sources because an oxidation reaction must occur prior to the formation of highly mobile forms of heavy metals. Still, HGR metals can corrode, producing metal oxides and salts that can produce mobile species. Such water-soluble forms of metals can form complexes with soil components that result in surface water or, more rarely, groundwater contamination.

Stormwater runoff can erode and transport contaminated soil and heavy metal particles away from a range. Rainfall intensity, ground slope, soil type, and obstructions such as vegetation and fabricated structures influence the potential transport of the metals with surface runoff. Analysis of unfiltered leachate and runoff samples has shown that substantially larger amounts of lead (Pb) were lost in the particulate fraction than in the filtered (0.45-µm) effluents from small arms ranges (Larson et al. 2005). Dissolved metals can also be found in some surface waters. Groundwater contamination can occur in areas with unfavorable soil pH, particularly in acidic conditions, or, as occasionally found in desert environments, conditions that are too basic. Although these are not TCLP-regulated metals (Congressional Federal Record (CFR) Title 40, Part 261), Zn, particularly, can raise environmental concerns if levels in surface or groundwater become substantial (ATSDR 2005). Both Fe and Zn form low solubility complexes with hydroxides (Revie 2000). The solubility product constant, K_{sp} (25 °C), for the most common iron oxide is 4×10^{-38} mol/L and for the most common zinc hydroxide is 1.2×10^{-17} mol/L (Revie 2000).

Environmental fate and transport of hand grenade munitions constituents

Brannon and Pennington (2002) summarized the fate and transport processes for explosives in soil and water, providing descriptors for dissolution, adsorption coefficients, and transformation rates. Many of the munitions constituents occurring on training ranges have slow dissolution rates and low partition coefficients with a high potential for long-term contamination of ground and surface water (Brannon and Pennington 2002; Lynch 2002; Phelan et al. 2002; Lever et al. 2005; Dontsova et al. 2006). The combination of a low, but reversible, sorption coefficient and the magnitude of contamination at many sites results in a high potential for continuous percolation of contaminated water from near-surface sources through the unsaturated zone to the groundwater. RDX has a low soil adsorption potential, which leads to a high potential for migration and contamination of groundwater (Brannon and Pennington 2002; Lynch 2002; Larson et al. 2008a). Jenkins et al. (2001) and Pennington et al.

(2001, 2002) reported RDX-contaminated groundwater from several sites, confirming the transport of potential energetics into groundwater.

The fate of metals in soils depends on the physical and chemical properties of both the specific metal and the soil. Metals occur in the form of discrete particles (intact munitions or fragments), as well as metal oxides or salts (weathering products) and dissolved metal or metallic complexes sorbed to the soil matrix. Transport is more likely when the metals are present in a soluble form, for example, at low pH levels. Significant downward migration of metals from the soil surface can also occur when the metal retention capacity of the soil is exceeded. The addition of lime increases the hydroxide content in the pore water, creating more metal hydroxides that precipitate and are not available for transport. Controlling soil and pore water pH with lime addition for alkaline hydrolysis of the explosives can also directly impact the fate and transport of metals associated with munitions constituents.

Current remediation technologies

The optimum treatment technology for successful remediation of distributed energetics and metals contamination on training ranges should be inexpensive, easily applied in remote locations, effective on heterogeneous contaminant distributions, effective over large areas, effective on multiple compounds, non-intrusive, to the extent possible, and able to be incorporated into normal range operations. Technologies currently available for the remediation of munitions-contaminated soil and groundwater were reviewed by Stratta et al. (1998), the National Research Council (NRC 1999), Rodgers and Bunce (2001), Weeks et al. (2003), the United States Government Accountability Office (GAO 2005) and the Federal Remediation Technology Roundtable (FRTR 2006). Few remediation alternatives are available to treat soil and sediments and most of these involve ex-situ treatment. Inherent in all ex-situ processes is the required excavation and transport of the contaminated soil with the associated health and safety risks. Ex-situ systems are often part of a treatment train and, as such, are expensive to initiate and often produce residuals that also must be treated (Weeks et al. 2003). Therefore, a minimally disruptive, in-situ technology is preferable. Two in-situ processes reviewed favorably by Rodgers and Bunce (2001) and the FRTR (2006) are enhanced bioremediation and phytoremediation. The length of time and the effects of climate on cleanup are disadvantages shared by these methods. Also, the disruption of the HGR soil that results from regular detonation of hand grenades makes the

sustainment of biological processes challenging. **In summary, no technology other than the one described in this report is currently available that can effectively remediate the HE contamination found on active hand grenade training ranges or to prevent transport of these contaminants into the groundwater.**

Unlike the hazardous organic contaminants associated with munitions residues, metals are not degraded or easily detoxified. The most commonly used treatment technologies for metals in soils on firing ranges include solidification/stabilization, excavation and offsite disposal, and soil washing (Larson et al. 2007b). Other remediation technologies include electrokinetics and phytoremediation (FRTR 2006). These technologies, however, do not meet the remediation requirements of an active firing range. In the case of HGRs, the metals present are not those that will result in the characterization of HGR soil as a hazardous waste if the explosives residues are not present. For this reason, a technology in which iron and zinc migration is minimized and RDX and TNT are transformed has the potential of avoiding remedial action and the closure of active HGRs.

Objectives

The overall objectives of this study were to evaluate and develop a management technology to control active grenade range contaminant mobility with the application of lime to the range at the field demonstration site, Fort Jackson, SC.

Two of four grenade bays were selected at the Fort Jackson HGR. One was treated with lime while the other was not (control). The following performance objectives for HGR management were monitored and evaluated during the field demonstration study:

1. Reduce RDX and TNT concentrations by greater than 90% in the pore water leaching from the source area based on baseline and control area concentrations.
2. Reduce RDX and TNT concentrations by greater than 90% in the surface water running from the source area based on baseline and control area concentrations.
3. Reduce metals (Fe, Zn, Mn, Cr, Pb (if present), Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the pore water leaching from the source area based on baseline and control area concentrations.

4. Reduce metals (Fe, Zn, Mn, Cr, Pb (if present), Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the surface water running from the source area based on baseline and control area concentrations.
5. Assess the overall effectiveness and potential side effects of the lime amendment technology, including the following:
   a. Evaluate explosives reductions and metals (total and dissolved) soil stabilization or reductions in the surface water and pore water samples. Compare results from the treated (lime added) and control (no lime added) impact areas.
   b. Maintain or reduce explosives concentrations in soil at the source area. (Since continuous loading of explosives will occur, maintaining explosives concentrations in soil below baseline levels is an appropriate objective.)
   c. Determine ability to maintain pH above 10.5 at the source area and below 12.5 outside the source area.
   d. Evaluate ease of use. Identify problems, if any, with amendment application and maintenance of the lime-amended impact area. Determine the mixing efficiency required and estimate the frequency of lime reapplication. Identify factors other than range use that may affect the maintenance frequency.
   e. Evaluate the human health risks, including occupational risks associated with technology installation, range use, and range maintenance.
   f. Determine transport characteristics by using calcium from the dissolution of lime as a tracer in pore water, surface water, soils, and air monitoring samples. Fort Jackson HGR soil has a naturally occurring low calcium concentration.

2 Experimental Design

The Fort Jackson HGR has four throwing bays. Initial soil samples were collected from each bay along with core samples to determine the preliminary explosives and metals concentrations of the HGR soil. Using the preliminary investigation, two bays were identified as highly comparable and selected for the study. Bay 2 was used as the control and, after the installation of sampling equipment, operated as usual. Bay 4 was the test bay where lime was applied to the soil after the installation of sampling equipment.

Five suction lysimeters were placed approximately 1.52 m (5 ft) below ground surface (bgs) under the main impact area for each test bay. In addition one sump was placed under the main impact areas for each test bay. Two surface water samplers were placed in the main runoff flow areas of Bays 2 and 4. Sumps and lysimeters were placed three months prior to actual liming in order to obtain baseline data for explosives and metals in pore water and surface waters.

On the basis of research by Jenkins et al. (2005, personal communication) and Johnson et al. (2006, personal communication), 25 point composite soil samples were collected from eight sampling areas (numbered 1 to 8) within each bay, homogenized, extracted, and analyzed. Twenty-five point composite soil samples were also collected from three sample areas located on the range but offsite from the main impact area of the bays (numbered 1 to 3).

Explosives extractions were performed on the HGR soils following SW 846 (USEPA 1999), Method 8330, and analyzed for RDX, TNT, and associated byproducts. Where appropriate, pore water and surface water samples were concentrated using solid phase extraction (SPE) methods. Soil samples, digested per USEPA SW 846 Method 3051, and liquid samples were analyzed for soluble metals using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Multiple air samples were collected from the control and test bays during training exercises. They were analyzed for calcium, used as a tracer for the lime propagation as dust due to the detonations.

3 Materials and Methods

This study was undertaken to determine the effectiveness of lime application to reduce the concentrations of munitions constituents released during live hand grenade training. The munitions constituents of concern in this study were RDX and metals, particularly iron and zinc (Larson et al. 2008b, in review). During the course of the 20-month demonstration, soil samples, pore water, surface water, and air samples were collected, along with meteorological (MET) data, to determine the effectiveness of lime as a management approach to reduce migration of munitions constituents from the range.

Study site – Fort Jackson, SC

The Fort Jackson HGR is illustrated in Figure 1, superimposed with the soil, pore water, and runoff water initial sampling areas. The Fort Jackson range typically operates 5 days a week throughout the year. Approximately 55,000 hand grenades are thrown per year for training purposes on the range. During the field demonstration the “boom count” or the number of hand grenades thrown per test bay was recorded daily and averaged approximately 13,750 grenades per test bay per year. Range maintenance at the Remagen HGR during the field demonstration consisted of the reapplication of top soil during the slow training periods (typically twice a year around the months of December/January and June/July). In addition, the bay impact area was re-graded to smooth out divots when deemed appropriate by the range managers and range cadre personnel.

In selecting the field demonstration test bays at the Fort Jackson HGR, Bay 3 was eliminated due to the pooling of water that has a tendency to occur on that bay. Bays 1 and 2 were positioned next to one another and the collection of individual surface water samples from these two bays would not be feasible as the runoff water is combined at a single point. Bay 4 provided a site where runoff could be collected and it was separated from the other two bays. For these reasons, Bay 4 was selected as the treatment test bay. Bay 2 was selected as the control or non-limed bay since it was used in the same training manner as Bay 4 and there was good separation from Bay 4. In general, the number of grenades that are thrown on Bays 1 and 3 are similar and the number thrown on Bays 2 and 4 are similar.

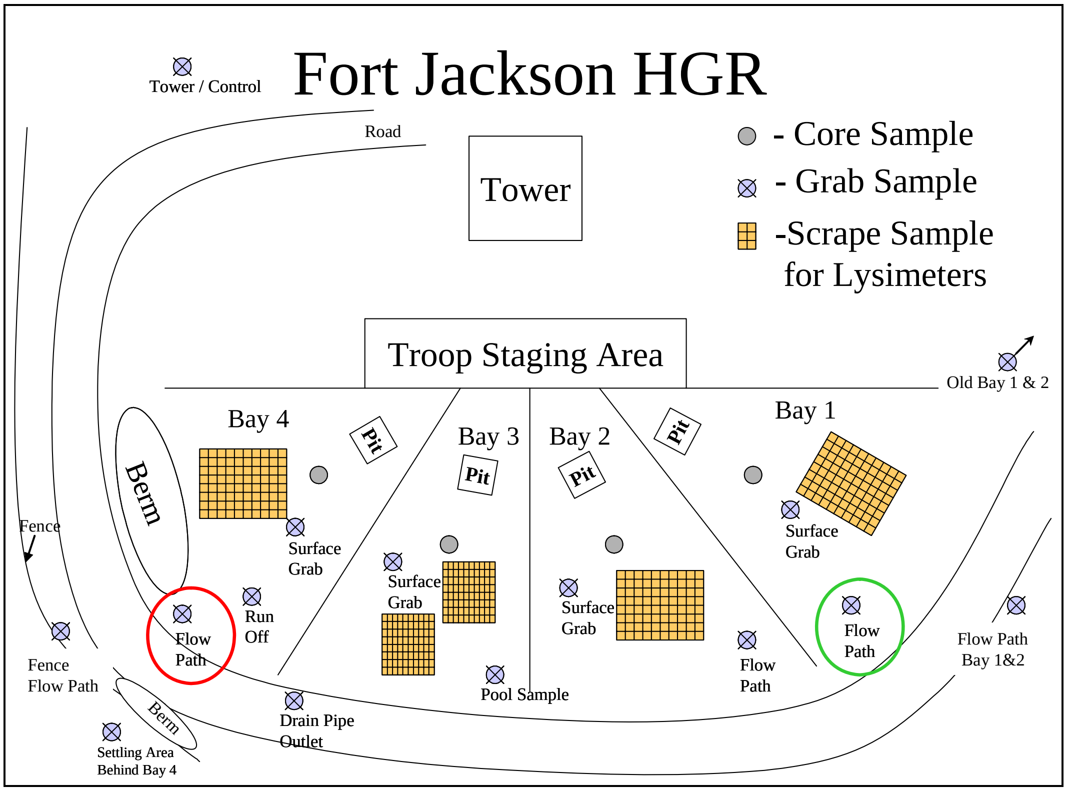

Figure 1. Schematic of the Fort Jackson HGR used to conduct initial sampling of the range for the treatability study (Larson et al. 2007a) and site selection (not to scale).

A rapid sampling procedure was devised that caused no impact to range training, so the limed and control bays were divided into eight sample areas (numbered 1 to 8) that ranged from approximately 42 m^2 (~450 ft^2) to 150 m^2 (1,600 ft^2) (Figure 2). Twenty-five point composite soil samples were taken within each sample area to a depth of approximately 7.62 cm (3 in.). Three offsite sampling locations (numbered 1 to 3) within the range complex, but offsite from the individual bays, were selected for additional soil sampling. The offsite sample areas were located along the main flow path of the surface water runoff from each bay, with offsite 3 directly off of Bay 4 and offsite 2 directly off of Bay 2. Offsite 1 had a combined surface water flow path from Bays 1 and 2. Offsites 1 and 2 showed a pronounced surface water flow path. On offsite 3, on the other hand, surface water pooled in the sample area unless it overtook the small berm established near the fence line.

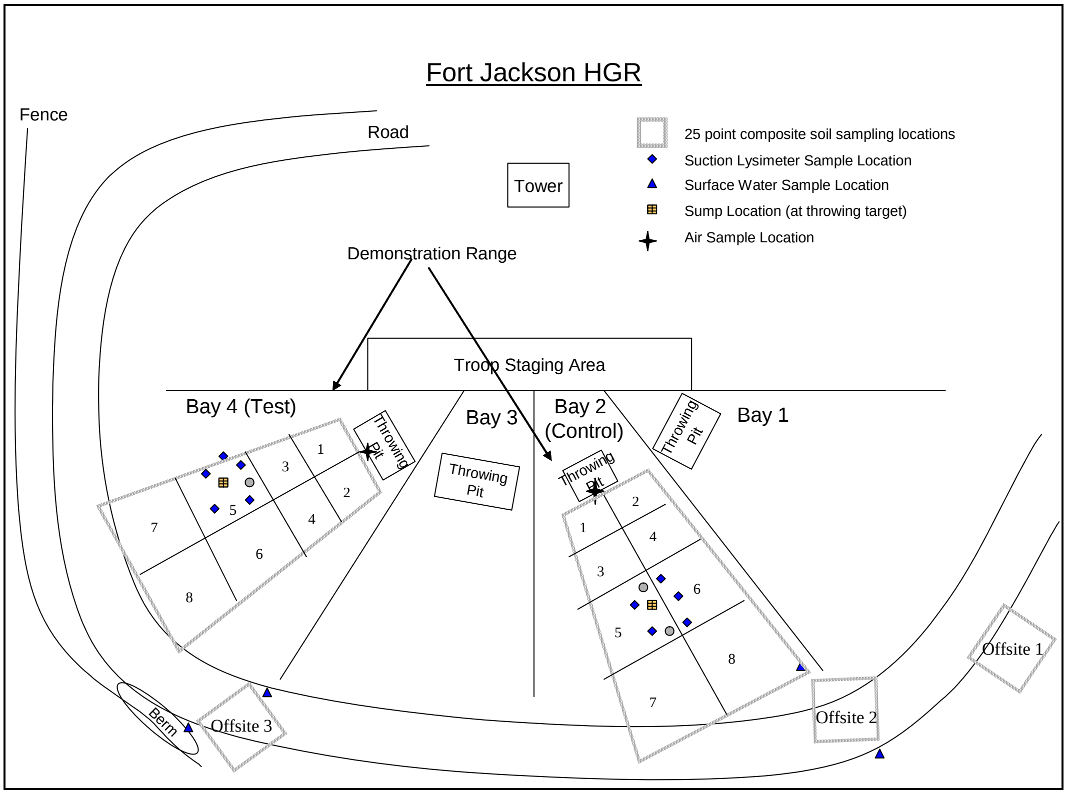

Figure 2. Schematic (not to scale) of Fort Jackson HGR; Bay 2 was the control and Bay 4 was the test bay (or limed).

Duplicate samples were taken during each sampling event for one of the eight sampling areas in each bay and for one of the three offsite sampling areas.

Soil sampling of both the limed and control ranges was performed prior to, and following, each lime application event and throughout the field demonstration. Initially, soil sampling was performed every month for three months. After month 3, sampling was performed once a quarter for the duration of the field demonstration. Standard maintenance practice at Fort Jackson is to fill in the divots created by the hand grenades on a regular basis, typically monthly, and apply new top soil on the range at least twice a year.

Physical and chemical analysis

Several methods and procedures used during this study are listed in Table 1 and summarized below.

Table 1. Chemical and physical analytical procedures used during the treatability studies.

Parameter/Procedure	Method	Detection Limit		
		Air, mg/m^3	Water, mg/L	Soil, mg/kg
Digestion procedures	SW-846-3051 APHA Method 3010	n.a.	n.a.	n.a.
Air samples	NIOSH Method 7300	0.01	n.a.	n.a.
ICP[a]	Method 200.7	n.a.	0.05	0.11
RDX/TNT	Method 8330 SPE	n.a.	0.0005[b]	0.01

n.a. = not applicable.

[a] ICP = inductively coupled plasma.

[b] Low levels due to SPE procedures.

The physical characteristics of the HGR soil were determined by standard laboratory procedures. Specific gravity, particle-size distribution, and soil classification were determined according to the American Society for Testing and Materials (ASTM 2001) procedures D-422, D-854, and D-2487, respectively. Chemical characterization of the HGR soil included explosives concentrations, digested metals content, total organic carbon (TOC), cation exchange capacity (CEC), and pH. The soil pH was measured in the field using pH paper and testing a slurry that was equal parts soil and water. The field pH values were verified in the laboratory with an electrochemical pH probe.

Explosives analysis

Soil samples were extracted and analyzed according to USEPA SW 846 Method 8330 (USEPA 1994). Explosives in runoff water and pore water leachates were analyzed using HPLC following 0.45-µm field filtering of samples to remove large particles. Where appropriate (i.e., sufficient volume available) low concentration liquid-phase samples were concentrated first using a solid phase extraction (SPE) technique. Pre-packaged cartridges of Propak (Sep-Pak, 6 cc, 500 mg) from Waters Corporation and a Visiprep solid-phase extraction manifold (Supelco) were used for the SPE procedure which was performed according to the manufacturers' instructions.

Metals analysis

The initial metals content of the area background soil taken near the cadre tower and the HGR bay soil was determined with the soil digestion procedure SW-846 Method 3051 (USEPA 1999). Pore water and storm runoff water samples were analyzed for dissolved metals after filtering through a 0.45-µm filter following the procedures in Method 3010 (APHA 1998) and determined with SW 846 Method 6010B for ICP-AES (USEPA 1999) on a Perkins Elmer Optima 4300 Dual View. The ICP metals reporting limit (RL) used in this study is 0.05 mg/L. The metals reported throughout this report are lead, chromium (Cr), copper (Cu), Zn, Fe, and calcium (Ca).

Statistical analysis was performed on data from Fort Jackson with SigmaPlot, ver. 10 and SigmaStat, ver. 3.5.

Preliminary soil collection and preparation

Several soil samples were collected from the Fort Jackson HGRs prior to the field demonstration. Bulk soil samples were collected from the Fort Jackson HGR (Figure 1) for use in the treatability studies and for initial site characterization (Larson et al. 2007a). The bulk soil samples were transported to the ERDC-EL (Vicksburg, MS) in 55-gal, polyethylene-lined drums (Figure 3). In addition to the bulk drum samples, several grab and core samples were collected. Grab samples were collected with a small scoop and then placed in plastic bags. The grab samples were used to determine the background soil characteristics near the range and the lime required to elevate the soil pH greater than 11.5. These grab samples were also used to determine preliminary soil characteristics and the applicability of the lime addition for range management. Fort Jackson HGR core samples were collected with a 5-cm (2-in.) internal diameter (ID) auger to a depth of 1.8 m (6 ft) bgs and were placed into plastic bags for transport to the ERDC-EL.

A composite sample of the contents of the drums was made after air drying the bulk soil samples. The air-dried soils were homogenized by hand in a large polyethylene-lined box using shovels, rakes, and a small hand tiller. Large rocks and organic debris were removed during the homogenization process. This soil was used in laboratory lysimeter studies prior to the field demonstration in order to establish the scale-up parameters (Larson et al. 2007a).

Figure 3. Collection of bulk soil samples from Fort Jackson HGR, three 55-gallon barrels were filled from each of the four bays.

Field demonstration

Pore water samples

Five pore water suction lysimeters (Figure 4) were placed approximately 1.52 m (5 ft) bgs under the main impact area targets in each throwing bay (Figure 2). In addition, one sump was placed in each bay under the main impact area of the bay. Pore water samples were collected prior to the field demonstration to establish baseline pore water concentrations and then were taken once a month for the duration of the field demonstration.

Figure 4. Pore water suction lysimeter below the main target area at the Fort Jackson HGR.

Surface water samples

Both HGRs had surface water samplers (Figure 2) placed at the edge of the bays to collect surface water as it flowed off of the impact area and into the surrounding range (Figure 5). The surface water samplers were triggered by water levels in the storm water runoff path. Surface water sample collection was attempted prior to the field demonstration to establish baseline concentrations and then attempted once a month for the duration of the field demonstration.

Air monitoring and meteorological (MET) data

Air monitors at the Fort Jackson HGR were placed in front of the throwing pits in Bays 2 and 4 for a total of six typical training days (24 hours). Six air samples were collected over several months and analyzed for Ca. Calcium was used as a tracer for the hydrated lime ($Ca(OH)_2$) in the dust associated with the hand grenade detonations.

Figure 5. Surface water samplers were triggered by rain events.

MET data were collected at Fort Jackson for 24 months. The temperature and rainfall directly affect the percentage moisture in the HGR soil, which controls the efficiency of the alkaline hydrolysis reaction responsible for transforming the explosives and stabilizing the metals.

Lime requirement

It was determined during the treatability study that an application of 1% lime (w:w) was needed to elevate the pH of the Fort Jackson HGR soil above the desired pH of 11.5 (Davis et al. 2007b). This equals 1 ton of lime. This amount of lime was added to Bay 4 and mixed to a depth of 15.24 cm (6 in.).

Lime application

Several techniques were used to apply the lime in Bay 4. These varied from simply opening bags on the range by hand and raking to give a uniform color distribution (Figure 6) to using a drop seed spreader (Figure 7). A hydroseeder was used for the final lime application in order to evaluate the effect of consecutive liming and watering. The lime was applied to the test range; it was then raked, and then watered (Figure 8). In order to mix the lime into the HGR soil to the required depth, several techniques were evaluated, including a garden rotor tiller, a small disc (Figure 9), a cultivator,

Figure 6. Opening and applying hydrated lime by hand.

Figure 7. Applying hydrated lime with a drop spreader.

Figure 8. A hydro-seeder was used after the final lime application to evaluate its effectiveness at wetting the soil.

Figure 9. Using a disc to mix the lime into the Fort Jackson HGR soil to a depth of approximately 6 inches.

and a rake (Figure 10). The treatability study conducted by Larson et al. (2007b) was not designed to determine the necessary frequency of lime application at the active HGR; this was determined while observing the trends (i.e., soil pH and explosives concentrations) during the field demonstration.

Figure 10. Using a cultivator and rake to mix the lime into the Fort Jackson HGR soil to a depth of approximately 6 inches.

4 Results and Discussion

The field data are presented based on the media in which they were collected: starting with the initial HGR characterization, followed by the general range parameters that were collected, then the soil samples, the surface water and pore water samples, and, finally, the air monitoring data. Supplementary data are presented in Appendices A to D.

Range characteristics

General soil characteristics

The soil characteristics of an HGR vary depending on the geographical location of the military installation and the sampling methods used to characterize the range soil (Jenkins et al. 2001). The Fort Jackson HGR soil characterization results are based on the initial grab samples (Table 2). It is common range management practice to introduce new top soil to the range while filling in divots and craters created by the detonation of the hand grenades. The soil conditions and properties that were determined during the initial soil sampling and characterization may not reflect the changes that have occurred during the field demonstration test due to range maintenance and management practices.

Initial HGR bulk soil metals concentrations

Offsite soil samples were collected near the Fort Jackson HGR tower (Figure 1) to provide background metals concentrations for an uncontaminated Fort Jackson soil. Fort Jackson HGR bulk soils (contaminated) were collected for use in the treatability studies (Larson et al. 2007a). Both soil types were first mixed to generate more homogeneous samples; then nine 200-g sub-samples were taken for metals analysis. The results are compared to reference soil metal concentrations for both the United States as a whole (Shacklette and Boerngen 1984) and the Eastern United States (O'Toole 1994) in Table 3. The only metal found at higher concentration than the U.S. mean and outside the range for the Northeastern U.S. is Zn. Other metals found at higher concentration than the mean but within the normal range are Pb and Ni. As could be expected, the majority of the metals concentrations in the throwing bay area are higher than the background metals concentrations as in this report we analyzed metals found as constituents of hand grenades.

Table 2. Soil characterization of Fort Jackson HGR soil.

Property	Fort Jackson
Specific gravity	2.62
Percent gravel	0.5
Percent fines	22.3
Percent sand	77.2
Unified Soil Classification	SM
Total organic carbon (%)	1.24
Cation exchange capacity, (meq/100 g)	6.5
Native soil pH	5.48
Potassium (mg/kg)	<130
Sodium (mg/kg)	<130
Sulfate (mg/kg)	30
Total Kjeldahl nitrogen (mg/kg)	<104
Total phosphate (mg/kg)	<20
Ortho-phosphate (mg/kg)	<5.2
Nitrogen as ammonia (mg/kg)	<10
Nitrogen as nitrite/nitrate (mg/kg)	33.7
Sulfide (mg/kg)	<52
Aluminum (mg/kg)	<66

Table 3. Metals concentrations for U.S. soils compared to the uncontaminated and contaminated Fort Jackson soil samples.

Metals	Concentration, mg/kg					
	Mean Background Concentration for U.S. Soils[a]	Typical Eastern U.S. Background Levels[b]	Fort Jackson Background Soil (uncontaminated)		Fort Jackson HGR Soils	
			Avg (n=9)	SD	Avg (n=9)	SD
Iron (Fe)	18,000	2,000 – 550,000	4,095	1,187	9,761	919
Zinc (Zn)	48	9-50	41	3	934	138
Lead (Pb)	16	4 – 61[c]	2[e]	2	33	11
Chromium (Cr)	37	1.5 – 40[e]	4[e]	4	25	1
Manganese (Mn)	330	n.a.	18	7	24	4
Copper (Cu)	17	n.a.	1[e]	<1	17	1
Nickel (Ni)	13	0.5 – 25[d]	4[e]	<1	16	1
Calcium (Ca)	9,200	n.a.	55	7	75	16

n.a. = not analyzed.
[a] Shacklette and Boerngen (1984).
[b] O'Toole (1994).
[c] Average levels in undeveloped, rural areas.
[d] New York State background.
[e] IDL used to calculate average values that have '<' before the number.

Initial HGR bulk soil explosives concentrations

RDX

The average (n=5) Fort Jackson HGR grab soil concentrations of RDX from the four throwing bays ranged from 1.04 to 3.78 mg/kg. These concentrations were similar to the bulk soil concentrations that were observed by Larson et al. (2007a) in the treatability study, where the average (n=27) homogenized Fort Jackson HGR soil RDX concentration was 2.38 ± 0.98 mg/kg.

TNT

Although TNT makes up 39% of the high explosive in each grenade thrown, very little to no detectable TNT was found in the range soil from Fort Jackson. A measurable concentration was only detected in two out of three replicates from one of the five grab samples from Bay 2 (2.83 ± 3.04 mg/kg). No TNT was detected in Bay 4 or in the offsite background samples.

Meteorological data

The December 2005 MET data were not collected at Fort Jackson due to instrumentation difficulties, but the missing data were estimated on the basis of local weather data for the Columbus, SC area (World Climate Website, WCW). The high and low temperatures for the Remagen HGR were 101 °F in August 2006, and 24 °F in December 2005, respectively (Figure 11).

The average annual rainfall for the Columbus, SC area is approximately 48 in. per year (The Weather Channel 2007), and the total obtained at the Fort Jackson Remagen HGR during the field demonstration was approximately 33 in. from August 2006 to August 2007 (Figure 12). Temperature and humidity can play a key role in the soil moisture content and therefore in the performance of the tested liming technology.

Complete meteorological data can be requested from the report authors:

Email: EL-Inquiry@erdc.usace.army.mil

Mail: U.S. Army Engineer Research and Development Center
ATTN: Environmental Laboratory/Technical Director,
Environmental Quality Technology R&D Program
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

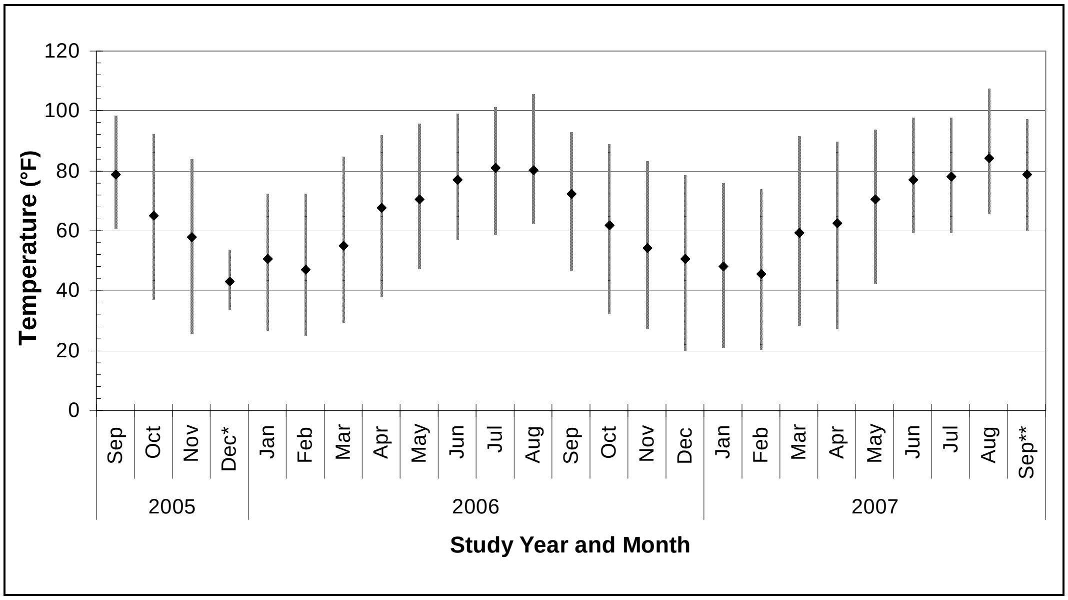

Figure 11. Average monthly temperatures with high and low temperature profile on the Fort Jackson HGR during the field demonstration (*indicates data completed from WCW website, **indicates a partial month).

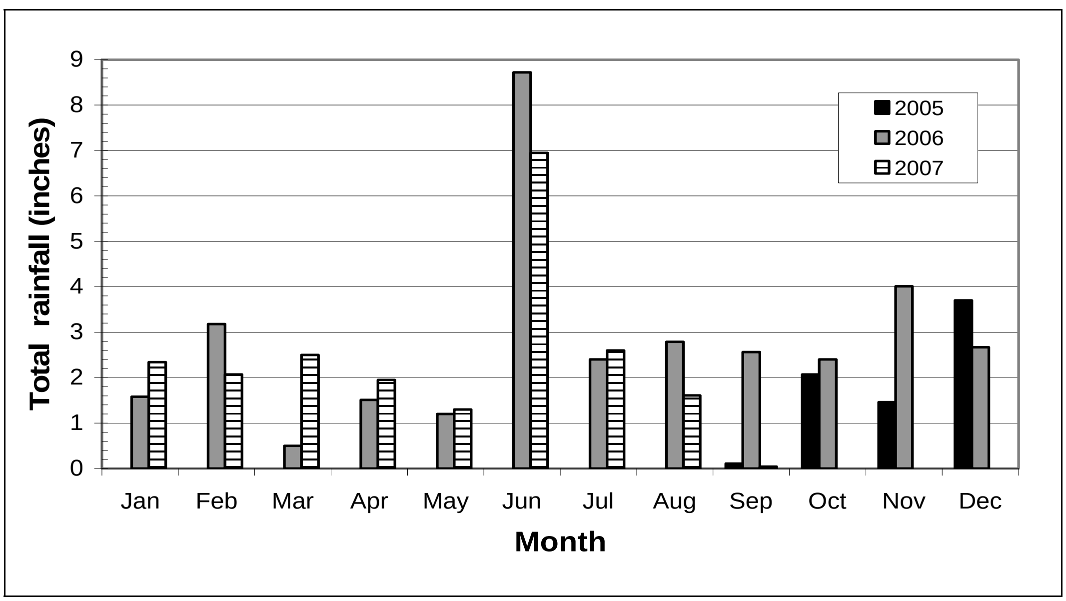

Figure 12. Monthly rainfall at the Fort Jackson HGR during the field demonstration.

Soil samples – Core samples

Soil core samples were collected from the Fort Jackson control and test bays. Core samples were taken to establish a depth profile for the soil moisture content and munitions constituents associated with the HGR and changes in soil pH as a result of the lime treatment.

Moisture content

The moisture content of the original core samples taken in July 2004 ranged from 2.96 to 7.86% moisture in Bay 2 and 3.61 to 5.65% moisture in Bay 4 (Table 4). Statistically, there is no significant difference between the soil moisture of Bay 2 and Bay 4 at the depths sampled through these cores.

Table 4. Average soil moisture content (%) of Fort Jackson soil core samples (n=3).

Depth, bgs	Soil Moisture Content, %	
	Bay 2	Bay 4
0–1 ft	4.86 ± 0.39	3.61 ± 0.11
1–2 ft	7.86 ± 0.32	5.46 ± 0.48
2–3 ft	5.96 ± 0.73	4.92 ± 0.09
3–4 ft	3.22 ± 0.09	4.94 ± 0.20
4–5 ft	2.96 ± 0.08	5.22 ± 0.34
5–6 ft	3.19 ± 0.07	5.65 ± 0.65

Soil pH

Core samples were taken to determine the pH profile within the soil. Initial pH of the Fort Jackson soil was determined to be approximately pH 5 to 6. A core taken from Bay 4 several months post-liming (April 2006) showed a pH profile that increased down to 12 in. bgs and then decreased to 30 in. bgs (Figure 13). The high pH was 10.14 ± 1.34; the low was 6.79 ± 1.38. This increase in pH in the 6- to 12-in.-depth is an important feature of the lime impact area at the Fort Jackson HGR. As RDX laden water percolates downward through the high pH zone, RDX transformation can take place. Over time, as the thickness of this high pH zone increases, the extent of RDX transformation will increase.

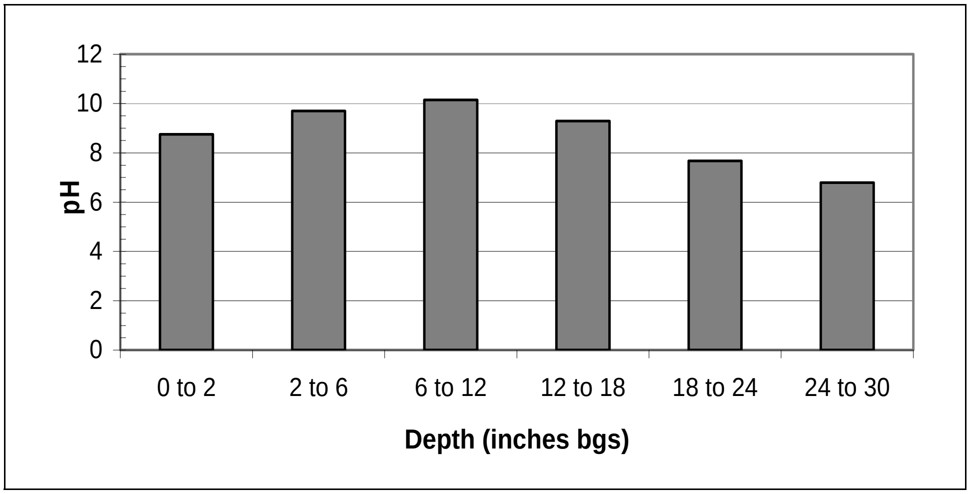

Figure 13. Post-liming core sample pH profiled for Bay 4, Fort Jackson.

Metals

Cores were taken from Bay 2 and Bay 4 to examine the occurrence of metals at increasing depth and determine the effect, if any, of the increased pH. The concentrations of metals from Bay 2 (the control bay) are listed in Table 5. The concentrations of metals found at increasing depth following several liming events (Bay 4) are listed in Table 6. As can be seen in Table 7, fewer metals occurred in Bay 4; the metals did not occur at the deeper depths of the soil profile, and there were fewer positive responses from the three replicates (i.e., many single values are reported. Non-detect values are reported as the MDL for the purposes of calculations.). Concentrations of naturally occurring Ca are low in the Fort Jackson soil, and the concentrations are consistent across the soil profile in the control bay (Table 5, Bay 2). As a result of the introduction of calcium hydroxide in order to elevate the pH, the Ca concentrations are higher in the surface 12 in. of the soil profile of Bay 4 (Table 6). The Ca concentration decreased to background levels at greater depths.

Lime treatment reduced the concentration of metals extractable from throughout the soil profile compared to the control values, significantly reducing the possibility of the metals migrating through the saturated zone to the groundwater. By reducing the extractable concentrations in the surface layer of soil, the possibility of metals being transported in the surface water is also greatly reduced (Objective 4).

Table 5. Metals concentrations by depth in a soil core taken from Bay 2 (n=3).

Metal	Concentration (mg/kg) by Depth, in. bgs											
	0–6		6–12		12–18		18–24		24–30		30–36	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Fe	7,778.67	1,686.22	8,680.67	768.52	9,420.67	1,568.58	7,548.67	2,515.01	3,354.67	1,430.64	1,514.00	256.15
Zn	1,303.77	925.21	958.70	268.74	1,005.00	243.06	5,617.33	7,583.71	353.69	311.63	59.55	32.65
Pb	21.24	0.01	18.44	1.36	16.39	3.09	16.50	3.28	5.28	8.95	0.11	0.00
V	14.66	5.14	11.76	1.63	16.33	2.73	8.34	14.25	0.11	0.00	0.11	0.00
Mn	14.46	1.86	18.19	4.29	23.11	2.49	21.44	1.97	10.97	10.00	0.11	0.00
Ni	11.22	0.67	10.63	0.55	8.09	6.92	7.63	6.64	0.11	0.00	0.11	0.00
Cr	13.56	2.65	12.78	0.89	14.90	2.22	8.56	7.75	0.11	0.00	0.11	0.00
Ca	59.37	26.71	49.45	0.44	57.66	19.06	63.85	28.38	36.64	7.43	72.81	70.59

Table 6. Post-liming metals concentrations by depth in a soil core taken from Bay 4 (n=3).

Metal	Concentration (mg/kg) by Depth, in. bgs											
	0-6		6-12		12-18		18-24		24-30		30-36	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Fe	3,794.00	1,438.26	4,464.50	1,427.65	2,043.50	399.52	1,749.00	223.45	653.06	923.40	1,347.50	267.99
Zn	1,138.35	222.95	768.50	615.89	19.58	3.18	20.78	0.13	21.95	10.73	17.21	1.82
Pb	22.24	6.70	11.71	16.40	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00
V	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00
Mn	6.17	8.57	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00
Ni	8.20	11.44	8.26	11.52	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00
Cr	5.70	5.70	5.86	5.86	0.11	0.00	0.11	0.00	0.11	0.00	0.11	0.00
Ca	3,333.50	1,513.92	663.65	704.77	59.49	3.30	60.63	3.77	59.57	20.87	55.51	0.04

RDX

The RDX concentration in the HGR bays was sampled by depth only once. That was the initial sampling event, prior to soil liming of Bay 4. The results are listed in Table 7.

Table 7. Soil RDX concentration profile by depth in the bay core samples.

Depth, ft bgs	Soil RDX Concentration, mg/kg	
	Bay 2	Bay 4
0–1	3.78 ± 2.09[a]	1.04 ± 0.34[a]
1–2	n.d.	0.47 ± 0.21
2–3	n.d.	0.46 ± 0.18
3–4	0.57 ± 0.001	0.97 ± 0.78
4–5	n.d.	0.59 ± 0.26
5–6	0.03 ± 0.03	0.84 ± 0.24

n.d. = not detected.

[a] Value obtained from the grab sample data, n=4.

Soil samples - 25 point composite samples

In order to represent the data collected, the average was obtained from soil samples taken initially, then every month for the first three months, and then on a quarterly basis.

Moisture content

The moisture content of the soil plays a key role in the efficiency of the alkaline hydrolysis reaction. Following the addition of lime in December 2005 and January 2007, there was a decrease in the soil moisture content, as shown in Table 8.

Table 8. Average soil moisture content (%) in Bay 2 and Bay 4 during the field demonstration.

Date	Bay 2 (Control)		Bay 4 (Limed)	
	Avg (n=8)	SD	Avg (n=8)	SD
6-Dec-05	10.48[a]	1.67	10.33[b]	2.67
7-Dec-05			6.98[c]	0.64
10-Jan-06	5.68	0.56	5.11	1.27
28-Feb-06	6.50	1.47	5.15	1.00
19-Apr-06	3.34[a]	0.23	0.56[b]	0.24
20-Apr-06			2.21[c]	0.42
18-Jul-06	0.49	0.31	0.31	0.17
12-Oct-06	5.77	0.83	6.36	1.02
19-Jan-07	9.23[a]	1.23	8.22[b]	0.38
20-Jan-07			6.83[c]	0.61
1-Mar-07	3.52	0.48	3.70	0.59
12-June-07	6.06[a]	0.32	5.93[b]	0.39
13-June-07			6.46[c]	0.38

[a] One sample per 2-day sampling event.
[b] Sample taken pre-liming.
[c] Sample taken post-liming.

Soil pH

The results of the field pH and the laboratory-verified pH for the first year of the field study are listed in Table 9. The pH paper is subject to interpretation by the user so there is some difference in the pH range from the paper to the probe. However, with experience, the soil pH can be determined using pH paper and can provide a guide for the reapplication of lime.

Table 9. Field and laboratory measured soil pH.

Date		Bay 2 (Control)		Bay 4 (Limed)	
		pH Probe	pH Paper[a]	pH Probe	pH Paper[a]
2006	Jan.	6.5	6.0	10.3[c]	12.0[c]
	Mar.	6.5	6.5	8.4[b]	10.5[b]
	Apr.	6.9	5.5	11.9[c]	12.5[c]
	July	6.6	6.5	7.8	9.0
2007	Jan.	6.4	6.3	8.0[b]	6.8[b]
				12.1[c]	12.3[c]

[a] pH paper is subjective and variable based on the interpretation of the user.
[b] Sample taken pre-liming.
[c] Sample taken post-liming.

The soil pH for Bay 4 varied depending on the application of lime, whereas the pH of Bay 2 soil remained relatively constant, around pH 7, throughout the demonstration. The limed bay, Bay 4, had high pH following the post-liming sampling events in January and April 2006, and January 2007. After that, the soil pH gradually declined until the next liming event (Figure 14 and Table 9). Based on this pH profile of decrease over time, to achieve the desired pH of greater than 10.5 to induce alkaline hydrolysis, a quarterly application rate of lime should be, and was, used (Objective 5c).

Metals

The hand grenade shell consists primarily of Fe, Zn, and other trace metals such as V, Mn, Ni, Cr, and Pb. Calcium was analyzed in order to track the presence of the hydroxide in the treated soil. The average concentrations of the metals in the two bays and the results of a t-test analysis of treatment significance are presented in Table 10. All metals demonstrated either a significant decrease (Fe, Cr, Mn, and V) or no change in extractability (Zn, Pb, and Ni) when treated with hydrated lime. This is illustrated in Figure 15 and Figure 16 for Fe and Zn, respectively.

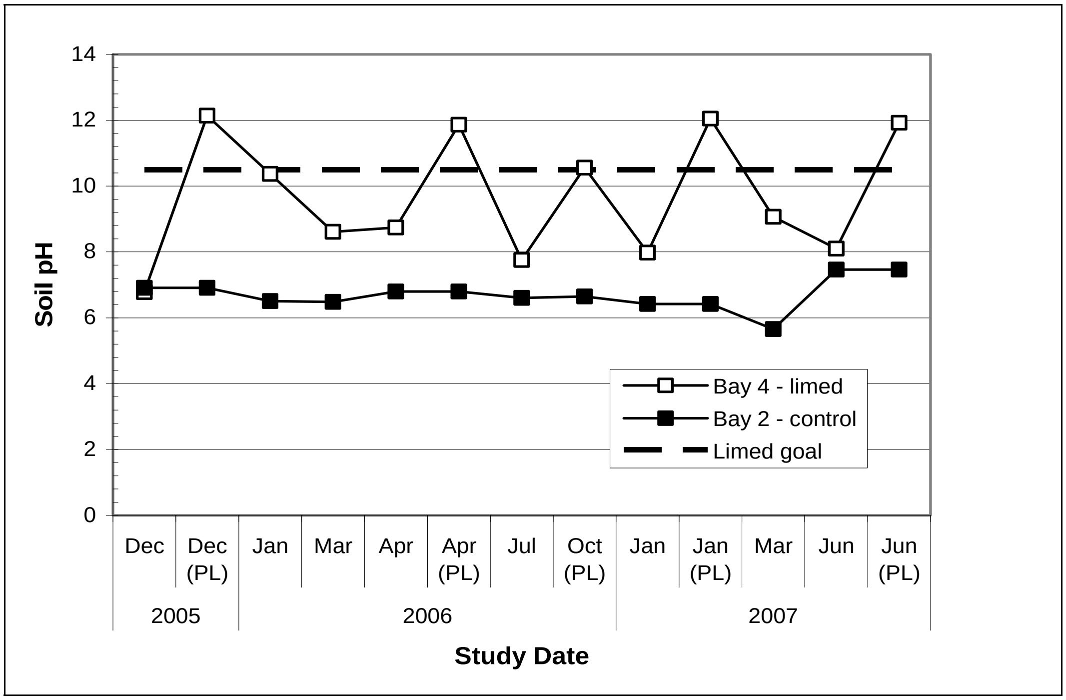

Figure 14. Soil pH profile for Fort Jackson, Bays 2 and 4 during the field demonstration (PL = post-lime).

Table 10. Average metal concentrations on a dry soil weight basis from Bay 2 (untreated) and Bay 4 (treated) throughout the field demonstration study at Fort Jackson, SC.

Metal	Bay 2		Bay 4		Significance
	Avg (n=8)	SD	Avg (n=10)	SD	
Fe	9,750.63	1,085.58	5,642.11	718.92	D
Zn	1,379.66	1,648.81	1,155.80	651.49	NC
Cr	16.68	1.41	11.13	0.75	D
Pb	23.17	0.84	20.73	1.38	NC
Ni	13.12	0.80	12.42	0.68	NC
Mn	19.35	2.97	14.82	2.22	D
V	19.07	1.45	14.28	2.23	D

D = significant decrease with treatment.
NC = no significant difference with treatment.

The treatment tracer, Ca, maintained an average concentration in the treated bay (Bay 4) of 7,745.90 ± 5,218.02 mg/kg over the duration of the field demonstration. This is in contrast to the Ca concentration in untreated bay (Bay 2) of 60.26 ± 31.98 mg/kg, a concentration within the background levels of the Fort Jackson Remagen range soil.

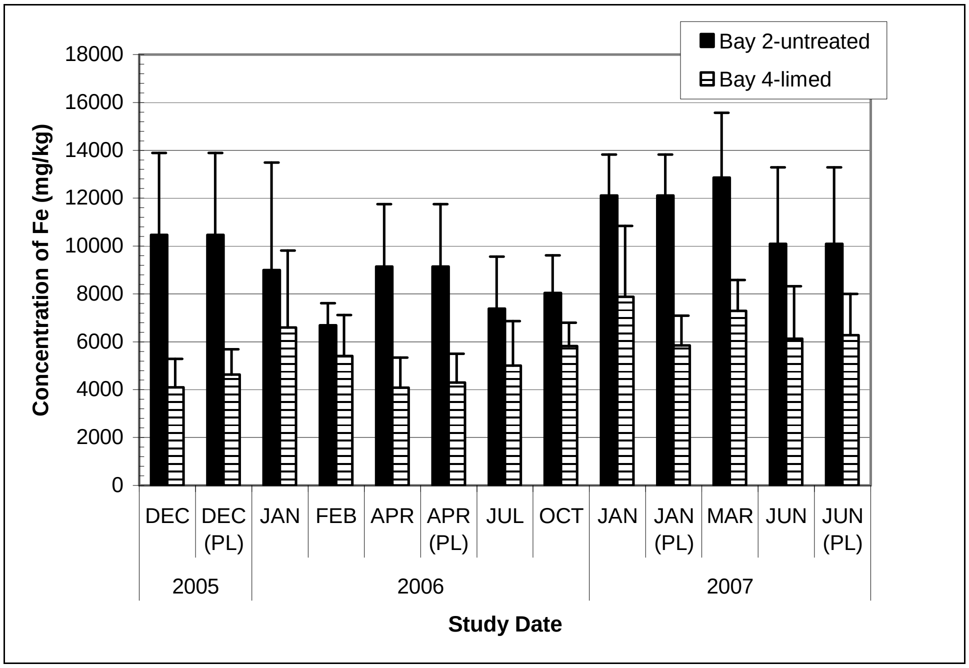

Figure 15. Average soil Fe concentration (dry soil weight) by bay (PL = post-lime).

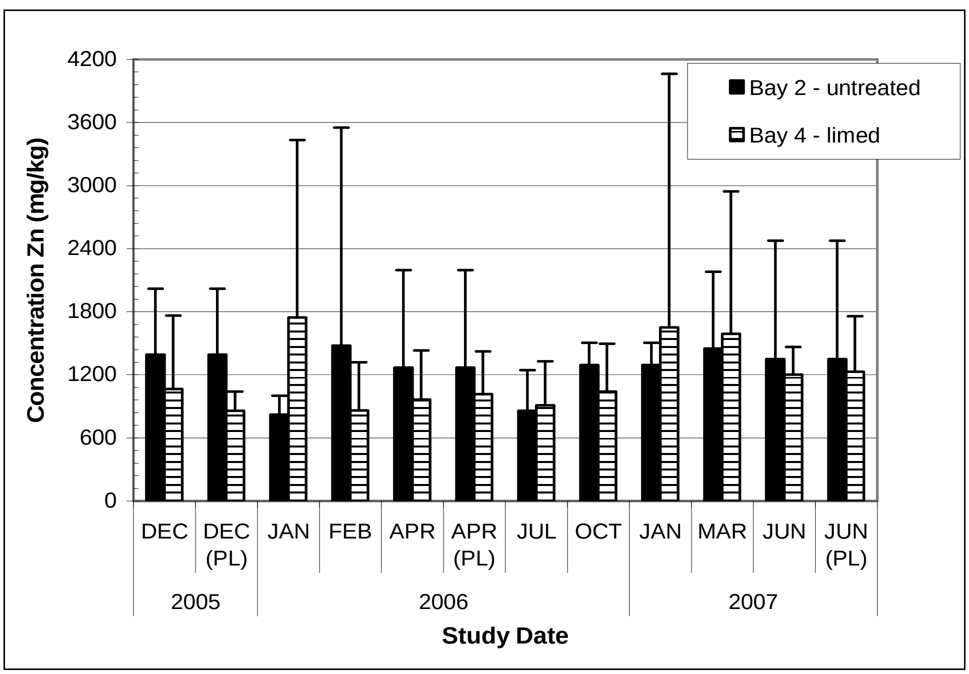

Figure 16. Average soil Zn concentration (dry soil weight) by bay (PL = post-lime).

RDX

The average soil RDX concentration per bay throughout the field demonstration is presented in Figure 17. There were low concentrations of RDX in the surface soil during the months of January 2006 and prior to the July 2006 sampling event due to range maintenance operations that placed additional top soil in the bays. The top soil was applied to fill in divots generated by grenade explosions and to adjust the surface water flow for Bay 2 (prior to July 2006). This addition of top soil places relatively clean soil on top of the treatment area resulting in a reduction of the soil pH in that area and, therefore, a reduction in the alkaline hydrolysis transformation of the explosive.

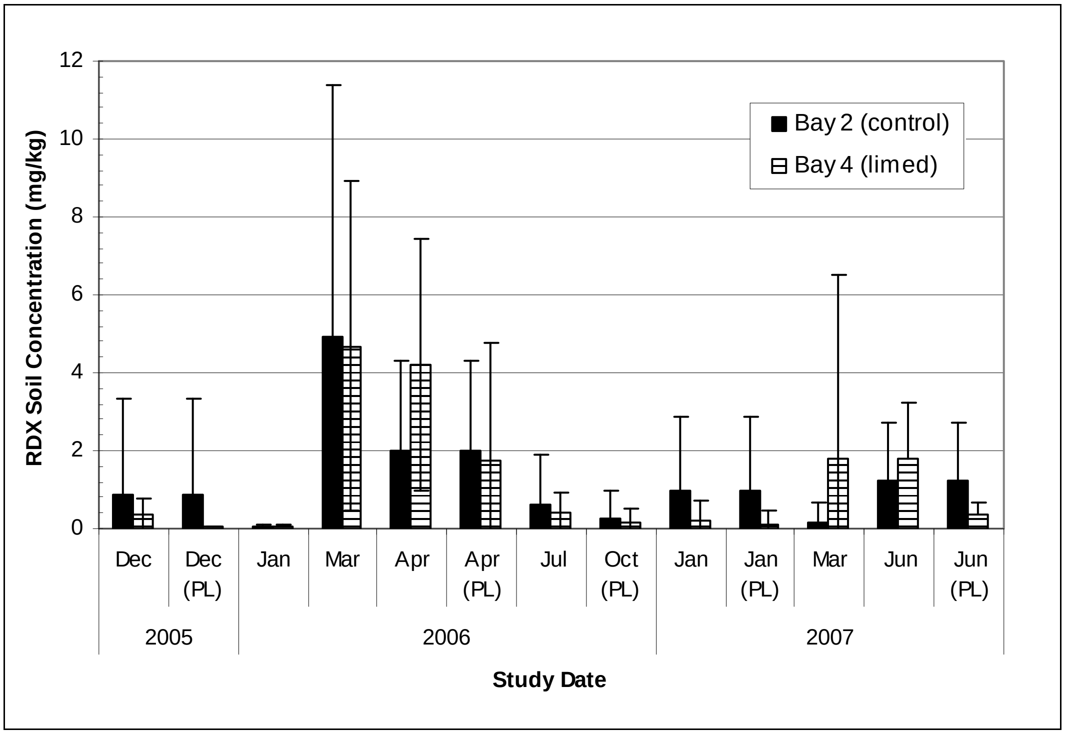

Figure 17. Average soil RDX concentration by bay during the field demonstration (PL = post-lime).

The average RDX soil concentrations in the eight sampling areas of Bay 4 over the duration of the field demonstration are listed in Table 11. In general, the average RDX soil concentration was decreased per bay sampling area with the addition of the lime to the soil. The decrease in the RDX soil concentration can be attributed to several factors including the alkaline

Table 11. Bay 4 pre- and post-lime soil RDX concentrations (n=3).

Sample Area	2005			2006			2007		
	RDX, mg/kg		% Decrease in RDX Soil Conc. [Increase]	RDX, mg/kg		% Decrease in RDX Soil Conc.	RDX, mg/kg		% Decrease in RDX Soil Conc.
	Dec (pre)	Dec (post)		Apr (pre)	Apr (post)		June (pre)	June (post)	
	6-Dec-05	7-Dec-05		19-Apr-06	20-Apr-06		7-June-07	8-June-07	
1	0.052	0.098	[87]	4.153	0.123	97	1.362	0.217	84
2	0.027	0.052	[89]	2.181	0.179	92	1.398	0.208	85
3	0.043	0.047	[9]	6.040	0.106	98	3.015	0.215	93
4	0.127	0.045	64	8.630	7.267	16	1.512	0.637	58
5	0.293	0.059	80	2.328	0.020	99	0.903	0.657	27
6	0.419	0.064	85	8.811	6.234	29	0.556	0.207	63
7	1.001	0.032	97	1.234	0.020	98	0.873	0.381	56
8	0.719	0.033	95	0.323	0.087	73	4.778	0.145	97

hydrolysis that occurred within the 24-hour period from the time that the soil was initially sampled to when the post-liming sampling occurred. The mixing of the lime into the soil also made the soil more homogeneous prior to sampling, reducing the sample variability.

When the soil pH fell below the treatment goal of 10.5, the RDX concentrations in the soil increased. The correlation of low surface soil pH (as seen in Figure 13) with the high concentrations of surface soil RDX (Figure 17) for March 2006, April 2006 (pre-liming), March 2007, and June 2007 would be expected. Maintaining the high surface soil pH involves a combination of sufficiently short lime application intervals and range management practices. This requirement can be minimized at a base hydrolysis reactive impact area range by incorporating the lime treatment into the regular range maintenance program through mixing lime with the top soil prior to its addition to the bays.

Soil samples - 25 point composite offsite samples

The offsite sampling areas were selected because they are the main surface water flow paths from each bay (Figure 2); with offsite 3 directly off of Bay 4 and offsite 2 directly off of Bay 2. Offsite 1 had a combined surface water flow path from Bays 1 and 2.

Moisture Content

The soil moisture content was similar to the bay moisture content except for offsite 3 where water pooled (Appendix A). The offsite 3 sampling area had an average moisture content of 8.54% versus offsite 1 and 2 with an average of 5.89% and 4.30%, respectively.

Soil pH

The offsite soil pH for locations 1 and 2 located near control Bay 2 (Figure 2) were similar to the pH of the control bay soil. They averaged slightly lower than the Bay 2 average, from 6.17 ± 0.48 to 6.29 ± 0.25, respectively (Figure 18). The offsite 3 average soil pH was 7.43 ± 0.58 (Figure 18) which is higher than that for the control bay, but still near neutral and within a range that it will not pose a risk to the surrounding environment. The offsite 3 soil pH was substantially less than the Bay 4 soil pH which ranged from 9 to 12.5 and the surface water runoff pH of 4.86 to 7.79. Since this offsite area was selected due to the runoff from Bay 4, it is promising that the surface runoff water pH appears to be buffered after traveling only a few meters to the offsite sampling area.

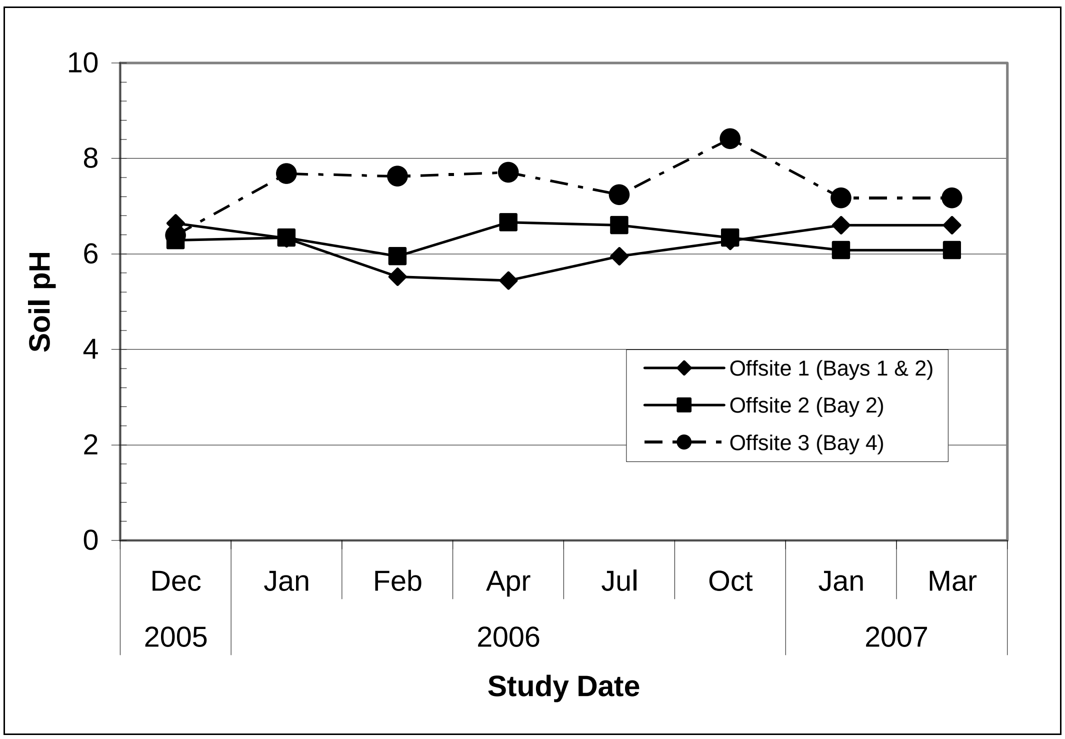

Figure 18. Offsite soil pH.

Metals

The occurrence of metals in the soil from the three offsite areas is summarized in Table 12. Copper was only detected in soil from offsite 3. Chromium was detected only once from offsites 1 and 2. Lead was detected once on offsite 1. These single detections all occurred at the same sampling event, March 2007. Lead present in the hand grenade primer may be the source, or the presence of the metals may be the result of sample cross-contamination prior to being received at the analytical laboratory.

Table 12. Average metal concentrations (mg/kg) from the three offsite sampling areas (n=8).

Metal	Offsite 1		Offsite 2		Offsite 3	
	Avg	SD	Avg	SD	Avg	SD
Fe	5,563.46	2,176.06	8,183.42	1,970.82	8,641.82	3,964.82
Zn	227.77	142.79	408.51	234.63	1,810.13	2,124.11
Cr	1.36	2.43	8.87	5.30	18.12	8.94
Pb	1.38	2.48	3.74	6.00	33.94	13.12
Ni	0.70	0.53	1.07	1.51	16.55	4.95
Mn	12.45	11.63	15.76	6.19	25.10	10.15
V	1.77	3.59	11.34	7.05	13.73	10.33
Ca	44.91	52.58	55.13	31.78	2,394.94	2,169.99

Calcium was tracked to determine the extent of its movement from the sampling area of treated Bay 4. Offsites 1 and 2, off the control bay, had very little Ca; the concentration found on offsite 3, off the treatment bay, was much higher. Average calcium concentration for offsites 1, 2, and 3 were 59, 55, and 2,395 mg/kg, respectively. The average Ca concentration in the Bay 4 soil was greater than 3 times higher than in the offsite 3 soil that received the Bay 4 surface water runoff. While the presence of the tracer in soils adjacent to the treatment area indicate that the calcium introduced into the soil as calcium hydroxide was transported by surface water flow, the absence of pH elevation indicates that the lime had dissociated and the hydroxide reacted prior to sampling of the offsite area. Calcium was not noted as being elevated in the other offsite areas.

RDX

The RDX concentration in the offsite sampling areas varied throughout the field demonstration. The average RDX concentration from the offsite sample areas 1, 2, and 3 from December 2005 through June 2007 were 0.4 ± 1.04, 0.5 ± 1.24, and 0.6 ± 1.13 mg/kg, respectively (Figure 19). The variance between replicate samples was generally very low, ranging from 0.0 to 0.2, until the June 2007 pre-liming sampling event. At that time, the RDX concentration in each offsite area increased significantly compared to the previous 17 months of soil sampling on these sites.

Possible migration pathways offsite for the RDX residues include leaching to groundwater and surface water runoff. The increased soil concentration in the three offsite sampling areas probably results from surface migration of RDX particulates to these sites. Offsites 1 and 2 were supplied by RDX from the control bay, Bay 2. Offsite 3 was supplied by the RDX from lime-treated Bay 4. A period of 6 months had elapsed between liming events (January 2007 to June 2007) and an increase in RDX soil concentrations on the impact area of Bay 4 is expected to be the source of this RDX.

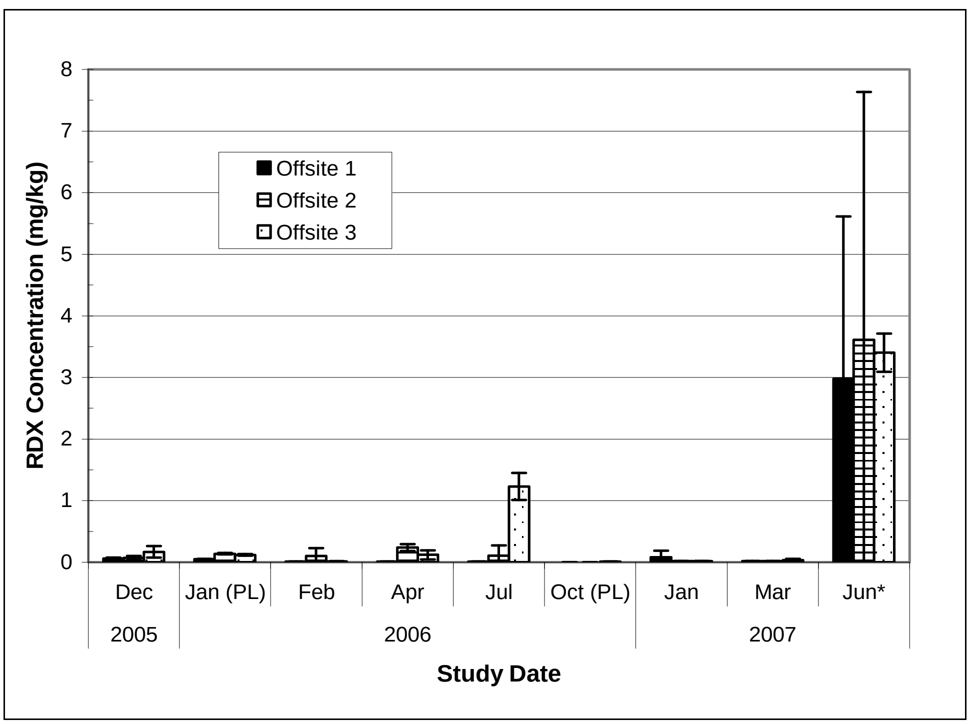

Figure 19. RDX concentration in offsite soil, n=3
(PL=post-lime, *indicates pre-lime sampling).

The difference in the concentrations is best explained by the surface water flow in each sampling area. For offsite sample areas 1 and 2, there is physical evidence (Figure 20) of the runoff water flowpath directly through the sample area. Consequently, there is little RDX deposition from the surface water and the RDX particulates are carried away from the sampling area. Offsite 3 does not have a flowpath through the sample area. Instead, in this sampling area, the surface water accumulates and particulates are deposited on the surface soil (Figure 21). The RDX concentration in the post-liming sample taken for offsite 3 in October 2006 was below detection limits. At this same sampling event there was no sample available for offsite areas 1 and 2 due to limited sampling time on the range.

Pore water lysimeter samples

A total of five suction lysimeters and one sump were placed in each test bay. Although collection was attempted, sump water samples were not obtained during the field demonstration due to equipment difficulties. The collection of baseline samples from the lysimeters was confounded by the unusual drought conditions in effect from June 2005 until October 2005 (Figure 11). Collection of pore water samples from the suction lysimeters was conducted on a monthly basis. The weather (i.e. the rainfall amount,

Figure 20. Offsite sample area 1 and 2 showing the pronounced flow path through the sample area.

Figure 21. Offsite sample area 3 illustrating the pooling of surface water that occurs in the sample area.

humidity, and the soil moisture content) affected the amount of pore water that was available for collection per sampling event. The volume collected ranged from no sample available to approximately 1 L, typically with the dry months having no to very little sample collected. Other measured field parameters of the pore water such as the volume collected, conductivity, turbidity, and redox value are reported in Appendix A.

pH

The pore water suction lysimeters were placed approximately 1.52 m bgs. During the field demonstration sampling, the pH of the pore water ranged from 5.67 to 7.59 for the lysimeters in Bay 4 and from 5.53 to 7.69 for the lysimeters in Bay 2. The average pH values for the pore water from the limed Bay 4 were slightly less than the average pH values for Bay 2, the control bay (Table 13). This satisfies Objective 5c, to assess the overall effectiveness and potential side effects of the lime amendment technology by maintaining the pH below 12.5 outside the source zone area.

Table 13. Pore water pH from the suction lysimeters.

Bay	Lysimeter ID	Pore Water pH	
		Avg[a]	SD
4	1	6.85	0.29
	2	6.87	0.68
	3	6.98	0.50
	4	6.93	0.40
	5	6.59	0.26
2	6	7.05	0.58
	7	7.07	0.60
	8	7.10	0.66
	9	6.85	0.26
	10	7.02	0.46

[a] Average sample size ranged from 4 to 9 due to available sample for analysis.

Metals

The soluble metals concentrations were determined for the soil pore water collected by the lysimeters in each bay. Of the metals whose extractability from soil was decreased by treatment with lime (Fe, Mn, Cr, and V), only Fe and Mn appeared in the soil pore water collected by the lysimeters. Of those metals whose extractability appeared unchanged by the lime treatment (Zn, Pb, and Ni), only Zn and Ni were found in the soil pore water. The effect of the lime treatment on these metals found in the soil pore water is shown in Figure 22. There was no significant difference in pore water pH between the two bays and that pH was near neutral. A comparison of monthly average concentrations of each metal in pore water from Bays 2 and 4 (t-test) showed no significant difference in concentration between the treated and the untreated bays; however, it can be seen that, overall, less Fe was leached from the treated soil than the untreated. An analysis of variance confirmed that the soluble metals concentrations are less variable and metals appear to be less mobile (i.e., more stabilized) in limed Bay 4 than in unlimed Bay 2. This fulfills Objective 3, to reduce metals concentrations by greater than 90% or demonstrate no significant increase in metals migration in the pore water leaching from the source area, based on baseline and control area concentrations.

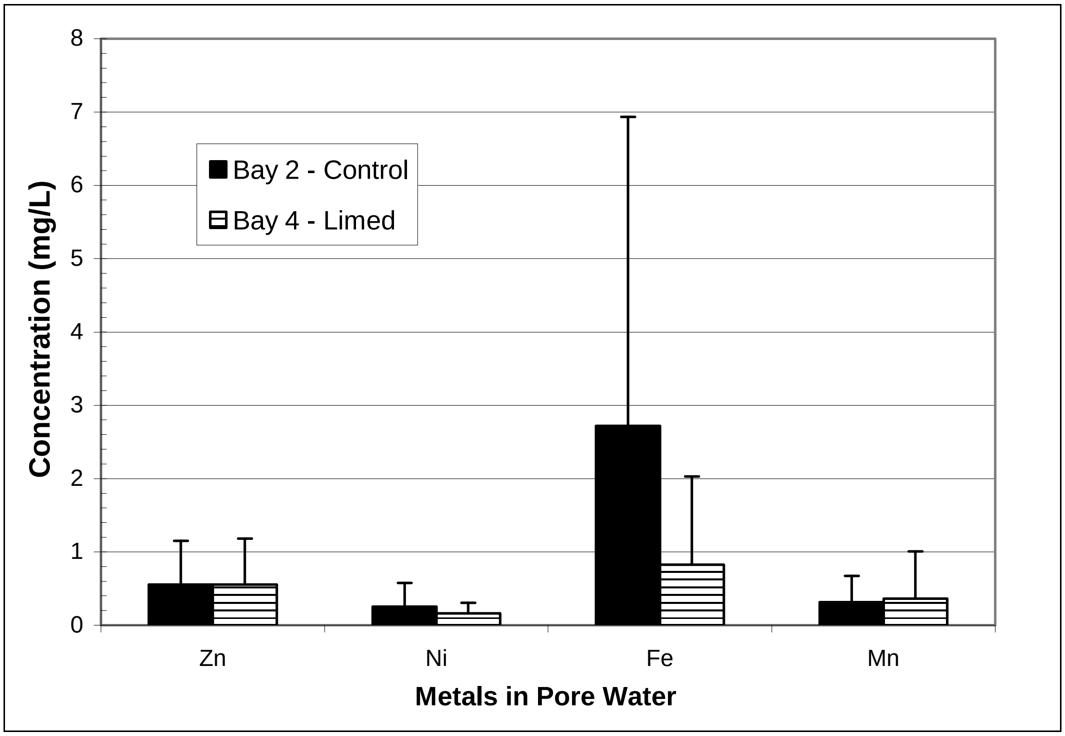

Figure 22. Concentration of soluble metals in soil pore water from treated and untreated HGR bays.

Calcium, used as a treatment tracer, was present in leachate from treated and untreated soil at 2.49 mg/L and 3.90 mg/L, respectively (Table 14), a statistically insignificant difference. The similarity of calcium concentrations in the two bays reflects the similarity in leachate pH. These data show that pH effects from the treatment are not significant beyond the source zone area and contribute to the fulfillment of Objectives 5c and 5f. Complete data on the Ca tracer are available in Appendix A.

RDX

Based on the average pore water concentration in the treated and untreated bays over the demonstration period, there was a 77% reduction in RDX concentration in pore water from the treated bay. One of the factors that required determination during the demonstration was the frequency of lime addition required to maintain treatment effectiveness. Because of this unknown engineering factor, there were extended periods of time during the study when soil pH in the treated cell was below the pH levels needed for RDX transformation. The average pore water RDX concentration was consistently less in limed Bay 4 than control Bay 2, throughout the duration of the field demonstration (Figure 23). There is a statistically significant difference between the explosives concentration in

Table 14. Concentration of Ca in the pore water obtained from lysimeters in the treated and untreated HGR bays.

Bay	Sample ID	Ca Concentration, mg/L	
		Average[a]	SD
4	L1	3.66	3.76
	L2	1.53	1.59
	L3	1.60	1.47
	L4	2.01	1.99
	L5	3.68	3.62
	Avg	2.49	
	SD	1.09	
2	6	4.49	4.61
	7	2.69	2.41
	8	3.11	2.22
	9	5.42	3.41
	10	3.77	3.09
	Avg	3.90	
	SD	1.09	

[a] Sample size (n) ranged from 4 to 9 due to available sample for analysis.

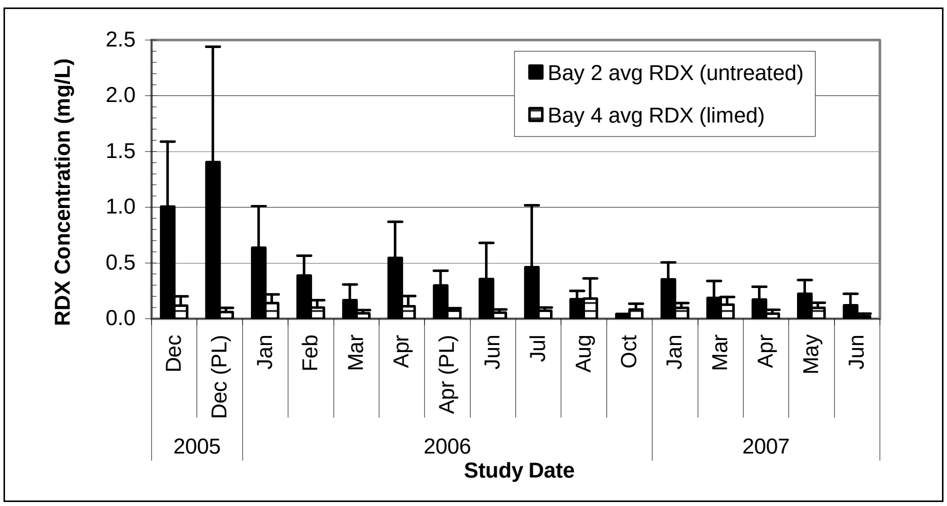

Figure 23. Concentration of RDX obtained from pore water suction lysimeters on the Fort Jackson HGR bays (avg, n=3).

the pore water from the untreated vs. the limed bays (P = <0.001). There was also less variability in sample concentration between the monthly averages from the treated bay than the untreated bay. In November and December 2006, no samples were available for analysis due to the temperature and weather conditions at the range; the lack of rain and drought-like conditions leading up to these sampling events limited the available pore water that could be extracted with the suction lysimeters.

Figure 24 shows the average, high, and low concentrations that were detected in each lysimeter during the field demonstration samplings. Figure 24 illustrates the very low variance recorded between samples from the treated bay vs. the high sample variance recorded between samples from the untreated bay.

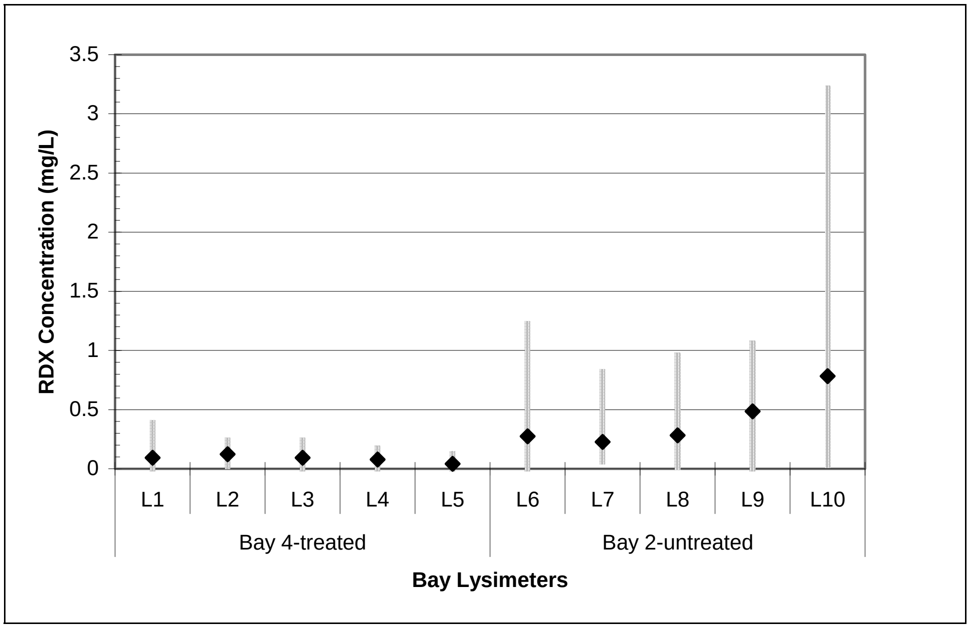

Figure 24. Pore water RDX concentration by bay and lysimeter with high and low concentration profiles (avg, n ranges from 7 to 10).

Objective 1 required that lime amendment reduce the explosives concentrations in the pore water leaching from the source zone by more than 90%, based on control and baseline samples. The average RDX concentration in the pore water from the untreated control bay, Bay 2, was 0.3597 ± 0.25 mg/L. The average RDX in the pore water from the five lysimeters of the treatment area over the course of the study was 0.0911 ± 0.04 mg/L, a 75% overall reduction. The lime treatment of Bay 4 achieved the 90% treatment goal in a number of individual sampling events, particularly in the later months of treatment. The consistent reduction of RDX leachate concentrations by 90% was not obtained as a result of reapplication rates that were too slow (initially) as well as range maintenance procedures (re-grading and spotty addition of topsoil) that reduced surface soil pH. Correlation of low surface soil pH shown in Figure 13 above with the high concentrations of leachate RDX for specific sampling events in Figure 23 would be expected. Maintaining sufficient surface soil pH involves a combination of sufficiently short lime application intervals and range management practices. At a base hydrolysis lime

impact area range, new soil must be amended with lime prior to filling divots, ruts, and holes. If unlimed soil is added, then surface soil pH in those areas will not be adequate for RDX transformation. The RDX concentrations by date for each lysimeter can be found in Appendix A.

The mass of RDX lost in the pore water can be calculated using the concentration and the volume of water collected at each sampling event (Figure 25). The total mass of RDX lost in the treatment bay is significantly less than in the untreated bay. The results shown in Figure 25 represent the mass of RDX in milligrams present in the volume of leachate water removed from each of the 10 lysimeters. Stacked by sampling date, the larger RDX losses present in both sets of lysimeters in January 2006 are clear and reflect the large volume of water collected throughout that month. Following periods of low rainfall, smaller volumes of water are collected and the resulting mass of RDX present in the leachates collected is low. The volume of water collected by each lysimeter during each month of the field demonstration is recorded in Appendix A.

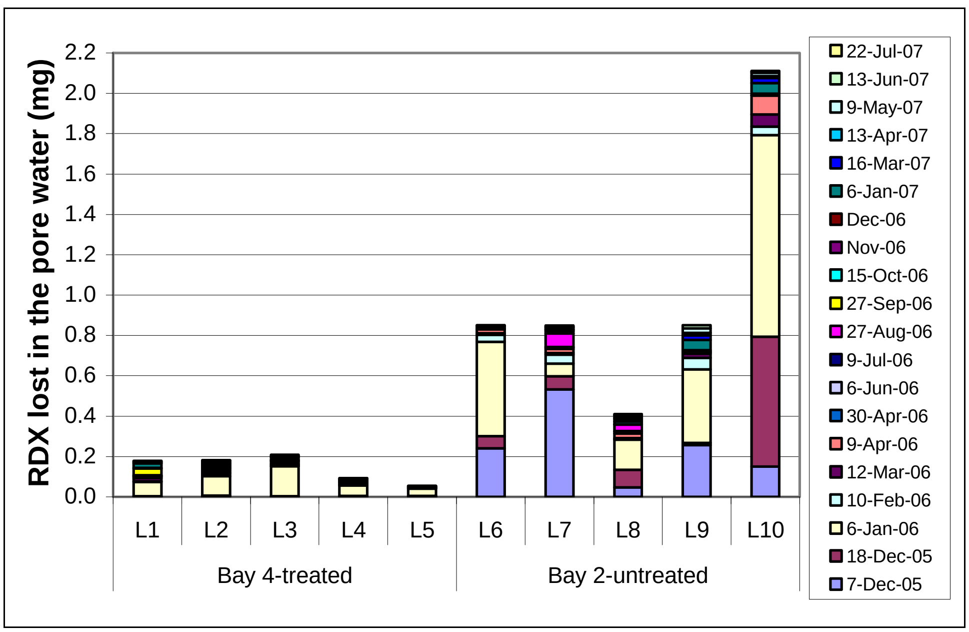

Figure 25. Mass of RDX lost per suction lysimeter during the field demonstration.

Surface water samples

During the field demonstration, surface water sample collection was affected by washout and build-up of silt within the sampler. The samples that were collected provide a qualitative view of the effects of Bay 4 liming as compared to the control, Bay 2.

pH

The surface water samplers were placed in the direct surface water flow path from each bay. During the field demonstration, the pH of the surface water collected from the Bay 4 samplers 1 and 2 ranged from 4.9 to 7.8. The pH for the surface water collected from the control Bay 2 surface water samplers 3 and 4 ranged from 5.4 to 6.6. Complete surface water pH data are available in Appendix A. These data meet the goals for Objective 5c, in which the overall effectiveness of the treatment would be assessed based on keeping the pH outside the source zone below 12.5.

Metals

Soluble metals detected in the surface water samples included Zn and Fe, as well as Ni and Mn. The most prominent metal was Zn, a major metallic component of hand grenades. The sporadic nature of the surface water samples supports only a qualitative examination of the data; however, initial samples from the untreated bay (Bay 2) indicate a Zn concentration of approximately 4 mg/L. The average of the final three surface water samples from the lime-amended bay (Bay 4) was 0.046 mg/L, a greater than 98% reduction. This value exceeds the goal, set in Objective 4, of greater than 90% reduction in soluble metals migrating from the HGR bay in the surface water runoff.

Calcium, used as a treatment tracer, was present in surface water from untreated soil at <5 mg/L. The calcium in surface water from the lime-amended bay (Bay 4) was also initially low, similar to Bay 2. However, this increased to approximately 30 mg/L over the course of the field demonstration. Complete metals data, including Ca, are provided in Appendix A.

RDX

The sporadic nature of the surface water samples supports only a qualitative examination of the data; however, initial samples of surface water from areas unaffected by the lime treatment indicate an RDX concentration of approximately 0.0095 mg/L (sample concentrations determined by SPE). Following the first liming event in December 2005, RDX concentrations in the surface water collection areas servicing Bay 4 decreased to 0.001–0.003 mg/L. These concentrations were maintained until April at which time the pre-liming samples of surface water from Bay 4 had increased to initial RDX concentrations. Lime treatment of Bay 4 resulted

in greater decreases in the RDX concentrations in the surface water, a condition which, again, persisted for 3 to 4 months. The final samples indicated a reduction in surface water RDX concentration from the control of >96%, which meets the goal of Objective 2.

Air Monitoring

As required by Objective 5e, the authors evaluated the health risks associated with the lime amendment technology. Just as in soil and water samples, Ca was used as a tracer for the presence of lime in the dust collected by air monitoring samplers. The instrument detection limit (IDL) of Ca = 0.01 mg/m^3. Detailed information about the air sampling data validation (Galston Laboratories) is presented in Appendix B. The air monitoring samples were collected during training activities on six separate occasions during the field demonstration. Although individual sample days produced some differences in Ca concentration, as seen by the averages and confirmed statistically, there was no significant difference in calcium concentrations between the air of the control bay and the limed bay as collected by the air monitoring equipment (Figure 26). This appears to indicate no harmful health effects towards the soldiers undergoing training.

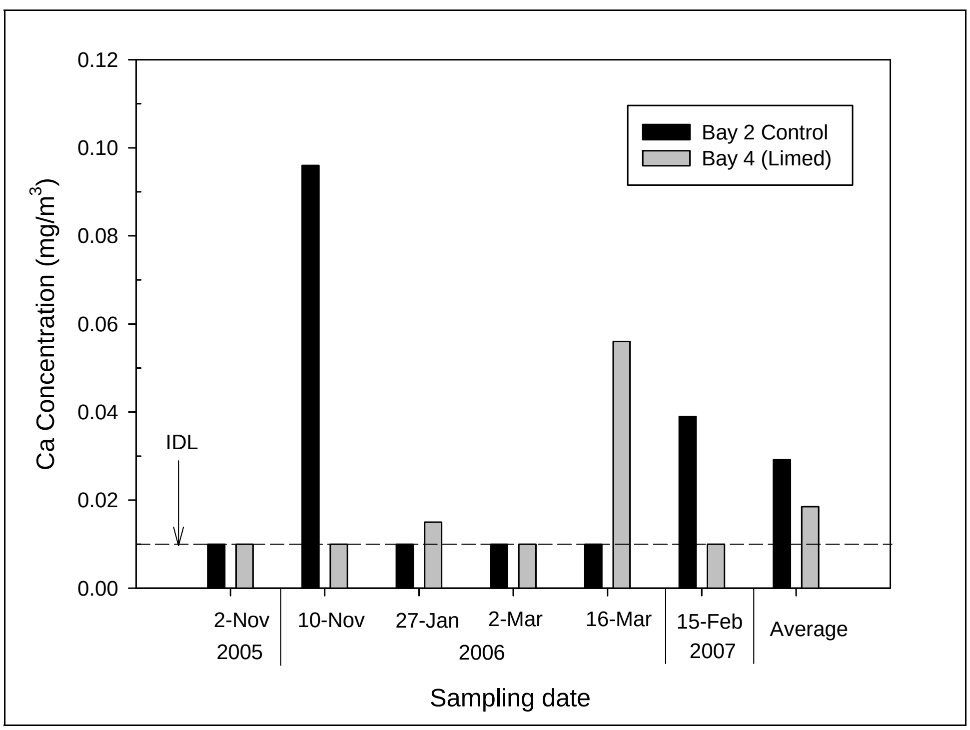

Figure 26. Comparison of Ca concentrations in air from treated and untreated bays during the field demonstration study (IDL=instrument detection limit).

This may also indicate that there would be no deleterious occupational effect associated with this installation method. The National Institute of Occupational and Safety Health (NIOSH) *Pocket Guide to Chemical Hazards* (2005) lists a recommended exposure limit (REL) time weighted average (TWA) and an OSHA permissible exposure limit (PEL) for respiratory exposure of 5 mg/m^3 for hydrated lime. The monitoring during training activities showed air concentrations much less than these exposure limits (maximum value obtained approximately 0.1 mg/m^3). Air monitoring during lime application activities was not performed during the demonstration. Protective clothing for skin protection and protective eyewear are recommended. Although not specifically required, ATC safety personnel also recommend a particulate respirator (dust mask) be worn during lime application. Washing skin and changing clothes at the completion of the lime application is also recommended as an alternative to wearing protective clothing. Air monitoring during lime application activities will be conducted during later work in this program to fully address potential personnel exposure.

Further discussion on the hazards associated with the hydrated lime treatment of HGRs can be found in Appendix C.

HGR usage

There are many factors that influence the concentration of RDX in soil and the effectiveness of the lime amendment. These include the number of grenades thrown on the range, as well as soil properties such as the pH, the precipitation at the site and the resulting soil moisture content (Table 15). The trends for Bay 4, observed from the data in Table 15, are represented graphically in Figure 27. A detailed discussion of the standard procedure for determination of the lime requirement for different soils for the alkaline hydrolysis of explosive compounds and metals is presented in Appendix D.

In general, for alkaline hydrolysis to perform effectively, the soil pH must be elevated above 10.5 and there must be sufficient moisture content (or precipitation) for the RDX and hydroxide to react. The advantage to dry conditions is that RDX will not become mobile in the surface or ground water, but reapplication of lime will be necessary in order to have the appropriate pH level when there is a rain event.

Table 15. Summary of the test bay properties and training activity as observed during the demonstration.

Year	Month	Bay 2 - Control				Bay 4 - Limed			
		Number of Grenades (boom count)	RDX (n=24) mg/kg	pH (n=8)	% Moisture (n=8)	Number of Grenades (boom count)	RDX (n=24) mg/kg	pH (n=8)	% Moisture (n=8)
2005	Oct	879	n.d.	n.d.	n.d.	1,089	n.d.	n.d.	n.d.
	Nov	1,213	n.d.	n.d.	n.d.	1,419	n.d.	n.d.	n.d.
	Dec	448	0.86	6.90	10.35	450	0.33 (0.05)[a]	6.78 (12.13)[a]	10.38 (7.00)[a]
2006	Jan	656	0.05[b]	6.51	5.63	654	0.06[b]	10.44	5.19
	Feb	382	4.94	6.48	6.75	380	4.68	8.54	5.20
	Mar	1,165	n.d.	n.d.	n.d.	1,242	n.d.	n.d.	n.d.
	Apr	717	2.01	6.89	3.35	719	4.21 (1.75)[b]	8.75 (11.83)[b]	0.52 (2.25)[b]
	May	542	n.d.	n.d.	n.d.	548	n.d.	n.d.	n.d.
	Jun	592	n.d.	n.d.	n.d.	458	n.d.	n.d.	n.d.
	Jul	1,318	0.59	6.59	0.49	1,181	0.43	7.76	0.32
	Aug	240	n.d.	n.d.	n.d.	240	n.d.	n.d.	n.d.
	Sep	1,805	n.d.	n.d.	n.d.	1,812	n.d.	n.d.	n.d.
	Oct	1,108	0.27	6.61	5.62	1,104	0.17	10.68	3.36
	Nov	978	n.d.	n.d.	n.d.	979	n.d.	n.d.	n.d.
	Dec[c]	1,447	n.d.	n.d.	n.d.	1,537	n.d.	n.d.	n.d.
2007	Jan	1,164	0.97	6.42	9.45	1,164	0.22 0.10[a]	7.95 11.60[a]	8.23 6.84[a]
	Feb	528	n.d.	n.d.	n.d.	528	n.d.	n.d.	n.d.
	Mar	1,693	0.15	6.34.	3.49	1,693	1.79	9.15.	3.77
	Apr	1,078	n.d.	n.d.	n.d.	1,078	n.d	n.d.	n.d.
	May	1,064	n.d.	n.d.	n.d.	1,064	n.d.	n.d.	n.d.
	Jun	747[c]	1.25	6.87	6.02	747[c]	1.80 0.33[a]	8.08 10.98[a]	5.93 6.46[a]

n.d. = not determined.

[a] Post-liming.

[b] Post-range work where top soil was applied to HGR.

[c] Partial month of data.

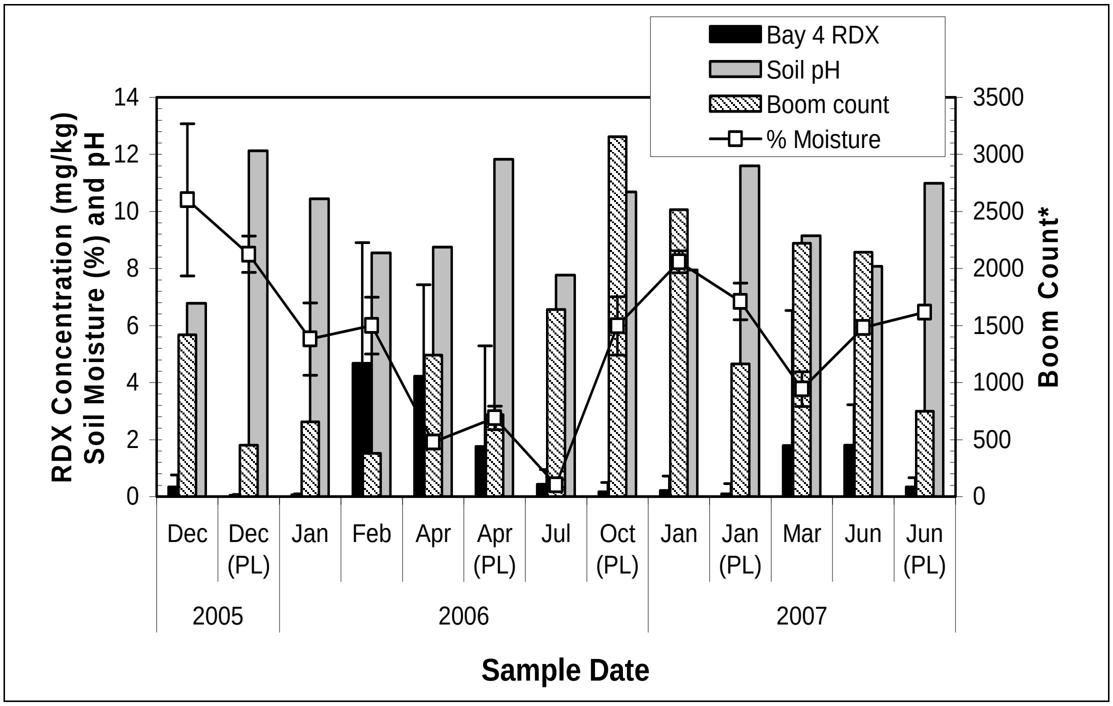

Figure 27. Bay 4 (limed) RDX soil concentration with soil pH and moisture and boom count. (*The boom counts are added together for the months that were not sampled.)

Months of poor performance (February and April 2006 and March 2007) have several factors in common. First, range maintenance operations were conducted in January each year and included filling divots with clean top-soil. This action decreases the pH of the entire topsoil cover and also creates areas of much lower pH. The second factor is the decreased rainfall in these months that resulted in lower soil moisture. The third factor is high usage rates in the months immediately preceding the sampling as determined by the boom count. This keeps the concentrations of the RDX at higher levels even though transformation is occurring, as evidenced by the low concentrations of RDX in the lysimeter pore water. The zone of high pH in the soil cores between 6 and 12 in. bgs is also evidence that RDX transformation can continue even when the surface soil pH decreases below optimal levels.

Attainment of the field demonstration study goals was evaluated through the metrics summarized in Table 16. The results of this study indicate that hydrated lime amendment to HGR soils was effective in achieving these goals.

Table 16. Summary of the performance objectives and results obtained from the field demonstration of alkaline hydrolysis for metals immobilization and explosives transformation at the Fort Jackson HGR.

Objective	Results
1. Reduce RDX and TNT concentrations by greater than 90% in the pore water leaching from the source area based on baseline and control area concentrations.	Based on the average pore water concentration in the untreated bay, there was a 77% reduction in RDX concentration in pore water from the treated bay. Individual sampling events achieved >80% reduction.
2. Reduce RDX and TNT concentrations by greater than 90% in the surface water running from the source area based on baseline and control area concentrations.	The final surface water samples indicated a reduction in RDX concentration of >96% from the control.
3. Reduce metals (Fe, Zn, Mn, Cr, Pb (if present), Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the pore water leaching from the source area based on baseline and control area concentrations.	Only Fe, Zn, Mn, and Ni were detected in the leachate from either bay. The concentration of Fe in the pore water was significantly decreased (70%) in the leachate from the treated bay. The concentrations of Zn, Ni, and Mn, were not significantly different, but they did not increase, in the treated bay.
4. Reduce metals (Fe, Zn, Mn, Cr, Pb (if present), Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the surface water running from the source area based on baseline and control area concentrations.	The only metal in the surface water samples above the MDLs was Zn. The average concentration of Zn in the final three surface water samples from the lime-amended bay (Bay 4) was 0.046 mg/L, a greater than 98% reduction from the control.
5. Assess the overall effectiveness and potential side effects of the lime amendment technology, including the following: a. Evaluate explosives reductions and metals (total and dissolved) soil stabilization or reductions in the surface water and pore water samples. Compare results from the treated (lime added) and control (no lime added) impact areas.	Decreased concentrations of RDX were detected leaving the range either in the pore water or the surface waters in the limed bay versus the control bay. There was also a decreased concentration of metals entering the pore water from the treated bay and the metals that did leach from the soil were detected at lower concentrations than the metals leaving the untreated soil. No metal detected in the pore water or the surface water increased in concentration as a result of the lime amendment.
b. Maintain or reduce explosives concentrations in soil at the source area.	Following the initial liming event, the RDX concentration in the treated bay decreased by 84% over the baseline, and 94% from the control. Across the impact area of the treated bay, RDX demonstrated a range of concentration that was decreased from the control by 23 to 97%.
c. Determine ability to maintain pH above 10.5 at the source area and below 12.5 outside the source area.	The pore water pH for the limed bay averaged slightly less than for the control bay. The pH of the surface water runoff collected from the limed bay remained at approximately 6.3. The offsite 3 surface soil pH averaged 7.4, approximately 1 SU above the control bay. Therefore, there was no evidence of impact from the lime outside the treated area.

Objective	Results
d. Evaluate ease of use. Identify problems, if any, with amendment and maintenance of the lime-amended impact area. Determine the mixing efficiency required and estimate the frequency of lime reapplication. Identify factors other than range use that may affect the maintenance frequency.	The application of the lime can be accomplished easily within a few hours with the proper tools and equipment. The cost of the lime was approximately $400 per application. It was determined that for the soil, climate, and range use conditions at the Fort Jackson HGR the bay would have to be limed on a quarterly basis to maintain the pH above 10.5 of lime addition are weather conditions on the range and frequency and type of range maintenance operations.
e. Evaluate the human health risks, including occupational risks associated with technology installation, range use, and range maintenance.	The air monitoring results indicated that the calcium (used as a tracer for the hydroxide) levels in the air samples from the limed bay were similar to if not the same as the calcium levels in the air samples from the control bay during training activities. Based on available data, it appears that personnel in training will not require any personal protective equipment. Application of the lime in the HGR bays requires only Level D personal protective equipment, modified by the addition of a particulate respiratory mask and, possibly, the substitution of goggles as protective eyewear. Range maintenance will require only Level D protection as the lime is incorporated into the soil at that point.
f. Determine transport characteristics by using calcium from the dissolution of lime as a tracer in pore water, surface water, soils, and air monitoring samples.	The Ca concentration in the post-liming core was elevated in the surface 12 in. of the soil. There was significant reduction in the Ca concentration, to background levels, in the samples taken at 12–18 in. bgs and below. This supports the pH data that indicate soil pH returns to background/neutral around 24 in. bgs. Pore water Ca values were comparable in the test and control bays. Surface water Ca from the test bay was elevated, but the pH was within the acceptable range. Soil in the offsite area receiving surface water runoff from the test bay also had elevated Ca, but the pH was not adversely affected, indicating consumption of the hydroxide ion.

5 Summary and Conclusions

Effective management of metals and explosives on HGRs requires an understanding of the natural and engineered processes controlling their fate and transport at these sites. The migration of metals and explosives, in both soluble and particulate forms, from the impact areas of the ranges occurs through a variety of mechanisms, including the following; transport in surface water following precipitation events, transport with soil particulates following precipitation events, and leaching through the subsurface towards groundwater.

The overall objectives of this study were to evaluate and develop a management technology to control active grenade range contaminant mobility and promote on site contaminant degradation with the application of lime to the range at the field demonstration site, Fort Jackson, SC. The contaminants, explosives and metals, would be transformed/degraded (explosives) or stabilized (metals) to permanently reduce the masses leaving the impact areas. In addition, the demonstrated technology would meet the criteria for active range management in that it would be non-intrusive and able to be incorporated into normal range operations. The technology would also be inexpensive, easily applied in remote locations, effective on heterogeneous contaminant distributions, effective over large areas, and effective on multiple compounds.

Hydrated lime was chosen as the soil amendment for its ability to transform explosives to environmentally friendly end products (Brooks et al. 2003; Davis et al. 2006, 2007a) and stabilize metals (Mckinley et al. 2001; Gray et al. 2006; Larson et al. 2007a). HGR soils were collected from Fort Jackson, SC for characterization and preliminary treatability studies (Larson et al. 2007a). A bench-scale study examined the soil lime dosing requirement. A mesoscale lysimeter study was conducted to scale-up the lime dosing test using the HGR soil with different lime concentrations and under varying environmental conditions before taking the technology to the field.

The following is a detailed summary of the objectives and results obtained from the field demonstration of the lime technology for explosives transformation and metals immobilization at the Fort Jackson HGR. Together,

the results indicate that lime addition can be a useful and effective technology for treatment of munitions constituents on ranges. Additionally, this method does not appear to pose adverse side effects to the surrounding environment if applied properly and monitored on a regular basis.

1. Reduce RDX and TNT concentrations by greater than 90% in the pore water leaching from the source area based on baseline and control area concentrations.

   Results: The optimal baseline explosives concentrations were not obtained in the 3 months prior to the initial liming event due to unexpected drought conditions. Although not optimal, semi-baseline values were obtained twice during the course of the study. Two lysimeter samples were obtained during a period when there was an inadequate lime concentration in the soil above the lysimeters. These two data points show that in Bay 4 significant masses of RDX would leach towards groundwater without the lime treatment. Untreated Bay 2 was used as the pore water control. As stated in the Results, based on the average pore water concentration in the untreated bay, there was a 77% reduction in RDX concentration in pore water from the treated bay. Individual sampling events achieved >80% reduction. Although this did not achieve the goal set in Objective 1, it was a statistically significant reduction in explosive concentration and confirmed that alkaline hydrolysis was capable of transforming the explosive residues from the hand grenades.

   No TNT was detected in the pore water lysimeter samples from either HGR bay.

2. Reduce RDX and TNT concentrations by greater than 90% in the surface water running from the source area based on baseline and control area concentrations.

   Results: As reported for the lysimeters, the baseline explosives concentrations were not obtained at all sites in the three months prior to the initial liming event due to the unexpected drought conditions. In addition, there was difficulty in obtaining surface water samples due to the soil clay and fine soil properties of the Remagen HGR. However, serving as a baseline, surface water samples were obtained for SW 1 both before and after the September 2006 liming event. Baseline samples were also obtained for SW 2 both before and after the December 2005 liming event. In these

events, there was a 60% decrease in the surface water RDX concentration. In addition, the offsite 3 soil RDX concentration went from 1.23 mg/L in July 2006 to non-detect (RL = 0.01 mg/L) in October 2006, or a greater than 99% reduction in the RDX concentration. Offsite 3 is where the water pools at the end of the Bay 4; there is potentially RDX lost as pore water leachate at the offsite sample area, but the offsite sample area did not have suction lysimeters as part of the field demonstration so this can not be confirmed. As stated in the results, the final surface water samples of the field demonstration indicated a reduction in surface water RDX concentration of >96%, from the control.

No TNT was detected in any of the surface water samples.

3. Reduce metals (Fe, Zn, Mn, Cr, Pb (if present), Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the pore water leaching from the source area based on base-line and control area concentrations.

   Results: Of the metals whose extractability from soil was decreased by treatment with lime (Fe, Mn, Cr, and V), only Fe and Mn were detected in the soil pore water collected by the lysimeters. Of those metals whose extractability appeared unchanged by the lime treatment (Zn, Pb, and Ni), only Zn and Ni were detected in the soil pore water. The concentrations of Zn, Ni, and Mn, were not, statistically, significantly different but they did not increase in the treated bay. The concentration of Fe in the pore water was significantly decreased (70%) in the leachate from the treated bay. Metals in the soil appear to be stabilized by hydroxide addition to the soil. This is also supported by the decreased variability between replicates in the metal concentrations in the pore water from the treated bay (Bay 4).

4. Reduce metals (Fe, Zn, Mn, Cr, Pb (if present), Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the surface water running from the source area based on baseline and control area concentrations.

   Results: The most prominent metal in the surface water samples was Zn. The average concentration of Zn in the final three surface water samples from the lime-amended bay (Bay 4) was 0.046 mg/L, a greater than 98% reduction from the control.

5. Assess the overall effectiveness and potential side effects of the lime amendment technology, including the following:

   a. Evaluate explosives reductions and metals (total and dissolved) soil stabilization or reductions in the surface water and pore water samples. Compare results from the treated (lime added) and control (no lime added) impact areas.

      Results: Decreased concentrations of RDX were detected leaving the range either in the pore water or the surface waters in the limed bay versus the control bay. The metals appear to be stabilized, i.e., there was a decreased concentration of metals entering the pore water and the metals that did leach from the soil were detected at lower concentrations than the metals leaving the untreated soil. No metal detected in the pore water or the surface water increased in concentration as a result of the lime amendment.

   b. Maintain or reduce explosives concentrations in soil at the source area. Since continuous loading of explosives will occur, maintaining explosives concentrations in soil below baseline levels will be an appropriate objective.

      Results: Soil samples were taken prior to, and 24 hours after, most liming events. Baseline RDX concentrations were established in December 2005 for each HGR bay. Following the initial liming event in that month, the RDX concentration in the treated bay decreased by 84% over the baseline, and 94% from the control, Bay 2. Soil moisture in each bay continued to drop with the lack of precipitation, hindering the alkaline hydrolysis reaction and allowing the RDX concentration in each bay to increase. With the resumption of rain and a liming event in April, the RDX concentration in the treated bay decreased significantly, from 4.2 to 1.8 mg/kg (a 57% decrease), while the concentration in the untreated bay remained constant (2.0 mg/kg). Across the impact area of the treated bay (Bay 4), RDX demonstrated a range of concentration that was decreased from the control by 23 to 97%.

c. Determine ability to maintain pH above 10.5 at the source area and below 12.5 outside the source area.

Results: It was determined that for the soil, climate, and range use conditions at the Fort Jackson HGR, the bay would have to be limed on a quarterly basis to maintain the pH above 10.5. The pore water pH for the limed bay averaged slightly less than for the control bay, indicating the hydroxide ion was completely neutralized before the leachate from the bay could impact the groundwater. The pH of the surface water runoff collected from the limed bay remained at approximately 6.3 for SW 1 and 2. The offsite 3 surface soil pH averaged 7.4, approximately 1 SU above the control bay. Therefore, there was no evidence of impact from the lime outside the treated area.

d. Evaluate ease of use. Identify problems, if any, with amendment and maintenance of the lime amended impact area. Determine the mixing efficiency required and estimate the frequency of lime reapplication. Identify factors other than range use that may affect the maintenance frequency.

Results: The application of the lime can be accomplished easily within a few hours with the proper tools and equipment. The cost of the lime was approximately $400 per application on Bay 4. It was determined that for the soil, climate, and range use conditions at the Fort Jackson HGR the bay would have to be limed on a quarterly basis to maintain the pH above 10.5. Additional factors that may affect frequency are weather conditions on the range, and frequency and type of range maintenance operations. In order for the munitions constituents to migrate off range there must be either rain or wind to transport the soil and associated munitions constituents. For example, in a dry region with little wind, the use of lime may be limited to known rainy seasons because munitions are not likely to be transported. Or in a very rainy area, the application rate of lime may be more frequent than quarterly due to the dilution and buffering effects associated with the weather patterns. In addition, the normal addition of top soil to the range to fill in divots or re-grade berms will dilute the lime and possibly give the soil additional buffering capacity. Additional liming should be considered along with these events.

e. Evaluate the human health risks, including occupational risks associated with technology installation, range use, and range maintenance.

   Results: The air monitoring results indicated that the calcium (used as a tracer for the hydroxide) levels in the air samples from the limed bay were similar to if not the same as the calcium levels in the air samples from the control bay during training activities. Based on available data, it appears that personnel in training will not require any personal protective equipment. This aspect is also under study in a follow-on study, lime treatment of OB/OD areas. Application of the lime in the HGR bays requires only Level D personal protective equipment, modified by the addition of a particulate respiratory mask and, possibly, the substitution of goggles as protective eyewear. Range maintenance will require only Level D protection as the lime is incorporated into the soil at that point.

f. Determine transport characteristics by using calcium from the dissolution of lime as a tracer in pore water, surface water, soils, and air monitoring samples. Fort Jackson HGR soil has a naturally occurring low calcium concentration.

   Results: Results from the preliminary soil analysis and from the soil cores, extracted pre- and post-liming, indicate that Ca is normally present in Fort Jackson soil at low concentrations. The Ca concentration in the post-liming core was elevated in the surface 12 in. of the soil. There was significant reduction in the Ca concentration, to background levels, in the samples taken at 12–18 in. bgs and below. This supports the pH data that indicate soil pH returns to background/neutral around 24 in. bgs.

   A comparison of the presence of the tracer Ca in the test media is summarized in Table 17 for the different areas of the Fort Jackson Remagen HGR during the field demonstration.

Table 17. Summary of the occurrence of Ca in the different media of the Fort Jackson HGR during the field demonstration (average Ca concentration (mg/kg or mg/L) by site and media[a]).

Bay 2 Soil	Offsite 1 Soil (Bay 2)	Offsite 2 Soil (Bay 2)	Bay 2 Lysimeter Leachate	Bay 2 Surface Water	Bay 4 Soil	Offsite 3 Soil (Bay 4)	Bay 4 Lysimeter Leachate	Bay 4 Surface Water
60.26 ± 31.98	58.91 ± 54.10	55.13 ± 31.78	3.68 ± 2.77	1.56 ± 0.72	7,745.90 ± 5,218.02	2,394.94 ± 2,169.99	2.54 ± 2.69	9.75 ± 13.01

[a] See text and appendix for sample number used to determine each average. Minimum was three replicates for each sampling event.

Together, the results indicate that lime addition can be an effective treatment for munitions constituents on ranges, and this method does not appear to pose adverse side effects to the surrounding environment if applied properly and monitored on a regular basis.

The appropriate amount and frequency of hydrated lime application to a HGR is a useful technology to manage explosives on ranges. The field demonstration results indicate that for an active range used on a regular basis a quarterly or biannual application of lime will be sufficient as a range management tool to reduce the migration of munitions constituents.

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Appendix A: Fort Jackson Field Samples

Soil characteristics

Table A1. Soil moisture content for Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Soil Moisture, %												
		7-Dec-05	18-Dec-05	Jan-06	Feb-06	9-Apr-06	30-Apr-06	Jul-06	Oct-06	Jan-07	Jan-07 (PL)	Mar-07	Average	SD
4	1	10.17	5.99	5.85	5.44	0.61	2.05	0.15	5.55	8.48	7.09	3.89	5.02	3.13
	2	11.44	7.92	5.89	5.94	0.31	2.96	0.38	5.38	8.36	6.48	3.44	5.32	3.38
	3	9.96	7.00	5.27	4.69	0.36	1.85	0.26	5.89	7.59	6.22	4.34	4.86	3.03
	4	16.39	6.81	4.72	4.65	0.27	2.29	0.25	6.84	8.25	6.39	2.86	5.43	4.52
	5	8.74	7.23	7.04	6.34	0.76	2.25	0.35	5.14	8.53	6.73	3.75	5.17	2.98
	6	9.20	6.53	4.43	3.30	0.49	2.56	0.51	6.41	7.77	6.49	3.13	4.62	2.89
	7	8.34	7.93	5.33	6.44	0.88	1.75	n.s.	8.32	8.71	8.23	4.69	6.06	2.86
	8	8.84	6.56	3.00	4.79	0.45	2.32	n.s.	7.35	8.13	7.11	4.04	5.26	2.77
	Avg	10.38	7.00	5.19	5.20	0.52	2.25	0.32	6.36	8.23	6.84	3.77	5.10	3.16
	SD	2.62	0.68	1.19	1.05	0.22	0.39	0.12	1.09	0.38	0.65	0.61		
2	1	n.s.	11.13	5.36	8.09	n.s.	3.26	1.10	5.05	9.71	n.s.	3.25	5.87	3.48
	2	n.s.	10.36	5.29	5.95	n.s.	3.10	0.49	4.96	10.28	n.s.	3.32	5.47	3.44
	3	n.s.	10.30	5.96	6.60	n.s.	3.48	0.39	6.20	8.49	n.s.	3.83	5.66	3.09
	4	n.s.	9.54	4.86	6.60	n.s.	3.34	0.44	5.38	10.21	n.s.	4.29	5.58	3.20
	5	n.s.	11.24	6.11	8.83	n.s.	3.45	0.38	6.30	10.57	n.s.	2.91	6.22	3.85
	6	n.s.	11.54	5.77	7.04	n.s.	3.63	0.06	6.93	10.07	n.s.	3.27	6.04	3.73
	7	n.s.	9.38	5.61	6.44	n.s.	3.28	0.61	5.20	8.84	n.s.	3.32	5.34	2.94
	8	n.s.	9.28	6.09	4.47	n.s.	3.22	0.47	4.97	7.46	n.s.	3.69	4.96	2.71
	Avg		10.35	5.63	6.75		3.35	0.49	5.62	9.45		3.49	5.64	3.26
	SD		0.89	0.44	1.32		0.17	0.29	0.75	1.08		0.43		
Offsite	1	n.s.	5.78	17.32	3.54	n.s.	1.96	0.38	n.s.	6.33	n.s.	1.29	5.23	5.78
	2	n.s.	6.26	2.81	3.35	n.s.	2.23	n.s.	n.s.	6.83	n.s.	1.74	3.87	2.15
	3	n.s.	12.53	9.47	4.80	n.s.	3.50	0.60	14.80	14.05	n.s.	9.16	8.61	5.20
	Dup	n.s.		2.55	3.64	n.s.	2.73	0.79		6.50	n.s.	8.14	4.06	2.74

n.s. = not sampled.

Table A2. Soil pH for Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Soil pH																
		6-Dec-05 wet	6-Dec-05 dry	7-Dec-05 wet	7-Dec-05 dry	10-Jan-06 wet	10-Jan-06 dry	28-Feb-06 wet	28-Feb-06 dry	19-Apr-06 wet	20-Apr-06 wet	18-Jul-06 wet	12-Oct-06 wet	19-Jan-07 wet	19-Jan-07 wet	8-Mar-07 wet	Average	SD
4	1	6.74	6.39	11.93	11.93	10.29	11.2	9.5	8.18	11.98	11.98	7.94	10.33	7.52	11.9	9.99	9.85	2.03
	2	6.78	6.67	12.1	12.1	11.77	11.33	8.29	7.94	12.09	12.09	7.81	11.26	7.65	11.97	8.94	9.92	2.20
	3	6.68	6.51	12.02	12.02	11.05	9.82	8.19	7.83	12.01	12.01	7.73	10.76	7.72	12	8.35	9.65	2.14
	4	6.65	6.69	12.23	12.23	11.15	9.73	8.41	8.05	11.66	11.66	7.82	10.57	7.9	12.04	8.05	9.66	2.09
	5	6.78	6.56	12.26	12.26	8.14	9.08	8.06	7.68	12.15	12.15	7.81	10.25	8.29	12.14	9.19	9.52	2.15
	6	6.86	6.62	12.36	12.28	10.4	8.69	8.15	7.79	11.04	11.04	7.82	9.88	8.11	12.2	8.77	9.47	1.98
	7	6.67	6.54	12.01	12.01	11.26	11.2	8.21	7.83	11.95	11.95	7.56	11.58	8.06	12.21	10.92	10.00	2.20
	8	7.09	6.6	12.13	12.13	9.44	9.85	9.48	7.8	11.94	11.94	7.61	10.8	8.31	8.31	8.97	9.49	1.92
	Avg	6.78	6.57	12.13	12.12	10.44	10.11	8.54	7.89	11.85	11.85	7.76	10.68	7.95	11.60	9.15	9.69	2.01
	SD	0.14	0.10	0.15	0.13	1.17	1.02	0.60	0.16	0.36	0.36	0.12	0.55	0.30	1.33	0.92		
2	1	n.s.	n.s.	6.52	6.45	6.56	6.48	6.34	6.69	7.33	n.s.	6.42	6.3	6.23	n.s.	6.79	6.56	0.30
	2	n.s.	n.s.	6.55	6.6	6.63	6.26	6.67	6.32	7.29	n.s.	6.35	6.36	6.38	n.s.	6.33	6.52	0.29
	3	n.s.	n.s.	6.99	6.53	6.47	6.23	6.46	6.64	7.67	n.s.	6.7	6.59	6.39	n.s.	6.41	6.64	0.39
	4	n.s.	n.s.	6.8	6.58	6.35	6.25	6.47	6.51	6.41	n.s.	6.75	6.65	6.51	n.s.	6.23	6.50	0.19
	5	n.s.	n.s.	7.32	6.72	6.64	6.63	6.51	6.94	6.49	n.s.	6.92	6.98	6.5	n.s.	6.39	6.73	0.28
	6	n.s.	n.s.	7.05	7.05	6.55	6.34	6.57	6.87	6.93	n.s.	6.85	7.06	6.43	n.s.	6.19	6.72	0.31
	7	n.s.	n.s.	6.93	6.42	6.37	6.23	6.28	6.34	6.27	n.s.	6.37	6.75	6.39	n.s.	6.14	6.41	0.23
	8	n.s.	n.s.	7.03	7.03	6.5	6.29	6.53	6.79	6.7	n.s.	6.38	6.16	6.49	n.s.	6.27	6.56	0.30
	Avg			6.90	6.67	6.51	6.34	6.48	6.64	6.89		6.59	6.61	6.42		6.34	6.58	0.19
	SD			0.27	0.24	0.11	0.14	0.12	0.23	0.50		0.24	0.32	0.09		0.20		
Offsite	1	n.s.	n.s.	6.64	6.83	6.33	6.74	5.52	6.2	5.44	n.s.	5.95	6.275	6.6	n.s.	6.6	6.28	0.47
	2	n.s.	n.s.	6.29	6.8	6.34	6.32	5.95	5.72	6.66	n.s.	6.6	6.34	6.08	n.s.	6.08	6.29	0.32
	3	n.s.	n.s.	6.39	6.66	7.68	7.22	7.63	7.3	7.71	n.s.	7.24	8.41	7.17	n.s.	7.17	7.33	0.54
	Dup	n.s.	n.s.	n.s.	n.s.	6.29	6.62	5.56	5.56	6.74	n.s.	7.38			n.s.		6.36	0.71

n.s. = not sampled.

Metal concentrations in soil

Table A3. Concentration of Ni in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Ni, mg/kg													
		6-Dec-05	7-Dec-05 (PL)	Jan-06	Feb-06	19-Apr-06	20-Apr-06 (PL)	Jul-06	Oct-06	19-Jan-07	20-Jan-07	12-Jun-07	13-Jun-07 (PL)	Average	SD
4	1	12.86	0.50[a]	10.54	12.92	13.23	13.21	12.21	10.77	8.64	0.50[a]	13.42	12.88	10.14	4.72
	2	10.62	15.15	12.13	0.5	11.65	0.5	0.5	12.41	10.70	0.50	12.82	15.04	8.54	6.10
	3	12.74	12.43	11.55	12.21	11.24	0.5	0.5	13.85	9.57	0.50	14.51	13.67	9.44	5.54
	4	0.5	10.9	13.22	10.42	14	12.95	0.5	11.57	12.32	0.50	14.02	14.49	9.62	5.63
	5	0.5	12.96	10.65	11.96	10.7	10.91	0.5	16.49	15.38	12.31	15.18	13.08	10.89	5.21
	6	12.17	13.25	0.5	0.5	0.5	11.13	0.5	0.5	15.61	12.34	14.74	14.18	7.99	6.72
	7	13.09	10.09	10.41	10.67	14.80	10.78	0.5	11.23	15.55	10.71	13.21	13.64	11.22	3.84
	8	11.63	0.5	5.59	0.5	10.31	n.s.	0.5	12.75	12.65	13.89	15.23	12.73	8.75	5.83
	Avg	9.26	9.47	9.32	7.46	10.80	8.57	1.96	11.20	12.55	6.41	14.14	13.71	9.57	3.37
	SD	5.47	5.74	4.21	5.82	4.46	5.60	4.14	4.69	2.78	6.37	0.92	0.82		
2	1	17.43	n.s.	15.51	11.6	14.23	n.s.	0.5	11.06	10.80		14.92		12.01	5.21
	2	14.09	n.s.	13.29	0.5	12.34	n.s.	0.5	13.34	14.61		17.76		10.80	6.56
	3	11.54	n.s.	12.24	13.89	13.46	n.s.	10.44	15.00	17.52		17.26		13.92	2.57
	4	16.77	n.s.	12.38	11.28	13.04	n.s.	10.13	13.78	13.39		16.18		13.37	2.25
	5	13.38	n.s.	11.22	0.5	12.73	n.s.	0.5	15.91	12.07		15.20		10.19	6.17
	6	12.39	n.s.	11.92	0.5	14.05	n.s.	0.5	10.00	15.36		10.80		9.44	5.77
	7	n.s.	n.s.	0.5	0.5	0.5	n.s.	0.5	0.5	8.99		0.50		1.71	3.21
	8	n.s.	n.s.	10.19	0.5	10.05	n.s.	5.55	15.46	14.57		12.62		9.85	5.28
	Avg	14.27		10.91	4.91	11.30		3.58	11.88	13.41		13.16		10.43	3.99
	SD	2.37		4.48	6.13	4.55		4.49	5.05	2.72		5.61			
Offsite	1	0.5	n.s.	0.5	0.5	0.5	n.s.	0.5	n.s.	1.89	n.s.	0.50		0.70	0.53
	2	0.5	n.s.	0.5	0.5	0.5	n.s.	0.5	n.s.	4.49	n.s.	0.50		1.07	1.51
	3	12.48	n.s.	10.81	12.34	19.86	n.s.	12.88	18.65	21.94	21.94	20.22		16.79	4.57
	Avg	4.49		3.94	4.45	6.95		4.63	18.65	9.44	21.94	7.07		9.06	6.66
	SD	6.92		5.95	6.84	11.17		7.14	0.00	10.90	0.00	11.39			

PL = post-liming.

n.s. = not sampled.

[a] Below detection limits, the conservative value of 0.50 mg/kg , the MDL, was substituted for calculations.

Table A4. Concentration of Zn in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Zn, mg/kg							
		6-Dec-05	7-Dec (PL)	Jan-06	Feb-06	9-Apr-06	30-Apr (PL)	Jul-06	Oct-06
4	1	910.20	637.50	972.10	855.20	913.40	1,751.00	776.90	795.40
	2	1,070.00	942.70	807.50	756.70	2,220.00	1,214.00	570.30	1,353.00
	3	2,995.00	920.50	987.90	852.00	774.20	835.90	816.40	981.90
	4	610.20	928.50	1,294.00	644.10	1,043.00	863.40	1,771.00	2,110.00
	5	617.40	1,199.00	4,665.00	2,040.00	906.00	676.20	1,025.00	1,106.00
	6	1,212.20	837.50	592.30	817.10	466.60	1,214.00	609.80	646.50
	7	714.25	723.00	567.80	705.90	925.05	562.00	600.80	693.90
	8	820.65	661.60	2,917.50	531.00	728.70	n.s.	1,006.30	831.40
	Avg	1,118.74	856.29	1,600.51	900.25	997.12	1,016.64	897.06	1,064.76
	SD	787.16	184.45	1,449.21	473.68	523.89	407.42	394.62	481.61
2	1	2,558.00	n.s.	1,170.00	817.10	3,634.00	n.s.	999.80	1,458.00
	2	999.60	n.s.	945.20	696.00	857.80	n.s.	670.70	1,439.00
	3	1,170.00	n.s.	832.30	1,095.00	873.00	n.s.	1,118.00	1,659.00
	4	786.70	n.s.	811.30	6,982.00	1,379.00	n.s.	996.60	1,205.00
	5	1,425.50	n.s.	807.40	656.00	1,412.00	n.s.	667.60	1,169.00
	6	n.s.	n.s.	910.30	878.40	599.90	n.s.	482.20	1,399.00
	7	n.s.	n.s.	593.10	503.50	850.60	n.s.	430.60	985.30
	8	n.s.	n.s.	660.55	840.00	708.60	n.s.	1,182.70	1,165.50
	Avg	1,387.96		841.27	1,558.5	1,289.36		818.53	1,309.98
	SD	694.67		177.28	2,198.35	991.76		291.57	215.63
Offsite	1	179.90	n.s.	170.00	105.54	100.30	n.s.	120.90	n.s.
	2	159.30	n.s.	449.55	529.70	252.50	n.s.	195.90	n.s.
	3	740.70	n.s.	691.50	729.80	1,240.50	n.s.	4,085.35	1,124.00
	Avg	359.97		437.02	455.01	531.10		1,467.38	1,124.00
	SD	329.89		260.98	318.76	619.05		2,267.54	0.00

Table A4. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Zn, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	629.20	632.90	604.20	842.50	921.57			864.77	295.31
	2	532.60	8,013.00	626.30	1,308.60	1,946.70			1,643.18	1,981.20
	3	327.60	421.00	733.30	1,336.20	2,334.87			1,101.29	749.46
	4	589.50	524.30	3,644.00	1,049.57	1,105.67			1,244.40	858.29
	5	2,434.00	1,304.00	4,205.00	1,629.00	999.67			1,754.33	1,298.87
	6	806.60	813.50	1,113.00	1,387.67	950.27			882.08	279.22
	7	905.80	679.50	1,351.00	859.77	928.17			785.92	213.31
	8	934.33	1,237.50	1,018.40	1,205.73	932.30			1,068.78	617.67
	Avg	894.95	1,703.21	1,661.90	1,202.38	1,264.90			1,167.59	304.14
	SD	654.14	2,569.29	1,427.37	271.45	553.72				
2	1	17,210.00	n.s.	1,119.00	1,045.27	n.s.			3,334.57	5,284.00
	2	1,057.00	n.s.	1,110.00	1,061.67	n.s.			981.89	232.65
	3	944.50	n.s.	1,042.00	1,226.33	n.s.			1,106.68	245.97
	4	1,062.00	n.s.	1,079.00	4,309.67	n.s.			2,067.92	2,143.33
	5	1,097.00	n.s.	2,404.00	1,178.00	n.s.			1,201.83	535.13
	6	975.20	n.s.	1,109.00	768.90	n.s.			890.36	287.84
	7	1,230.00	n.s.	915.40	613.57	n.s.			765.26	274.48
	8	679.45	n.s.	2,823.00	971.15	n.s.			1,128.87	715.20
	Avg	3,031.89		1,450.18	1,396.82				1,453.83	645.70
	SD	5,731.01		729.64	1,194.42					
Offsite	1	434.60	n.s.	270.20	447.37	447.37			252.91	151.48
	2	754.85	754.85	320.80	323.73	n.s.			415.69	224.26
	3	1,387.00	n.s.	1,516.50	1,248.67	n.s.			1,418.22	1,044.76
	Avg	858.82	754.85	702.50	673.26	447.37			659.16	342.23
	SD	484.64	0.00	705.40	502.14	0.00				

PL = post-liming.
n.s. = not sampled.

Table A5. Concentration of Fe in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Fe, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	5,947.00	6,546.00	5,126.00	4,037.00	5,434.00	4,645.00	3,979.00	5,096.00
	2	4,245.00	5,206.00	5,375.00	5,766.00	6,234.00	6,620.00	8,016.00	6,940.00
	3	3,166.00	5,442.00	1,3070.00	8,520.00	2,592.00	4,461.00	5,687.00	4,911.00
	4	2,631.00	3,351.00	6,818.00	5,813.00	3,625.00	4,127.00	2,903.00	7,644.00
	5	3,121.00	3,868.00	4,665.00	6,111.00	3,927.00	3,230.00	3,883.00	4,809.00
	6	3,954.00	4,286.00	3,875.00	3,843.00	2,772.00	2,903.00	6,916.00	6,157.00
	7	4,555.00	4,676.00	1,1000.00	7,120.00	4,998.00	4,143.00	6,676.00	5,086.00
	8	4,452.00	3,645.00	4,696.50	3,744.50	3,120.50	n.s.	3,477.00	5,864.50
	Avg	4,008.88	4,627.50	6,828.19	5,619.31	4,087.81	4,304.14	5,192.13	5,813.44
	SD	1,049.29	1,066.99	3,366.18	1,696.25	1,330.49	1,202.66	1,880.73	1,042.52
2	1	16,640.00	n.s.	13,090.00	8,364.00	3,634.00	12,080.00	6,665.00	9,377.00
	2	10,330.00	n.s.	15,690.00	7,388.00	9,887.00	n.s.	8,413.00	9,396.00
	3	8,624.00	n.s.	10,400.00	6,838.00	10,170.00	n.s.	6,263.00	7,243.00
	4	11,240.00	n.s.	9,869.00	6,982.00	8,618.00	n.s.	6,878.00	7,076.00
	5	6,541.00	n.s.	10,690.00	6,414.00	10,270.00	n.s.	5,498.00	7,767.00
	6	9,403.00	n.s.	8,248.00	5,654.00	10,120.00	n.s.	7,163.00	6,274.00
	7	n.s.	n.s.	6,943.00	7,137.00	11,120.00	n.s.	12,780.00	6,171.00
	8	n.s.	n.s.	6,005.00	5,686.50	6,432.00	n.s.	6,410.00	9,540.00
	Avg	10,463.00		10,116.88	6,807.94	8,781.38	12,080.00	7,508.75	7,855.50
	SD	3,425.33		3,181.26	897.75	2,526.13	0.00	2,287.71	1,406.87
Offsite	1	5072.00	n.s.	2,997.00	3,645.50	4,736.00	n.s.	8,247.00	n.s.
	2	6,021.00	n.s.	6,786.50	6,947.00	11,670.00	n.s.	9,875.00	n.s.
	3	5,344.00	n.s.	4,214.00	7773.00	8,403.50	n.s.	4,948.50	7,069.00
	Avg	5,479.00		4,665.83	6,121.83	8,269.83		7,690.17	7,069.00
	SD	488.69		1,934.73	2,183.97	3,468.93		2,510.01	0.00

Table A5. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Fe, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	11,700.00	6,358.00	7,392.00	7,632.33	4,146.67			6,003.00	2,094.26
	2	7,699.00	8,385.00	10,410.00	7,989.00	4,251.33			6,702.79	1,783.23
	3	9,095.00	6,034.00	7,025.00	7,550.67	7,959.33			6,577.92	2,776.05
	4	5,588.00	5,584.00	7,365.00	9,819.67	5,651.67			5,455.41	2,112.98
	5	6,568.00	5,378.00	6,291.00	5,336.00	8,619.00			5,062.00	1,558.72
	6	5,415.00	4,771.00	6,992.00	3,543.00	7,641.67			4,851.44	1,622.40
	7	4,725.00	4,460.00	7,174.00	4,277.67	6,101.00			5,768.59	1,903.86
	8	10,048.33	5,836.00	6,484.50	4,501.00	6,041.83			5,159.31	1,902.69
	Avg	7,604.79	5,850.75	7,391.69	6,331.17	6,301.56			5,689.33	1,203.45
	SD	2,484.29	1,201.68	1,281.02	2,217.75	1,660.11				
2	1	12,690.00		9,954.00	11,926.67				10,442.07	3,676.85
	2	13,790.00		15,490.00	13,336.67				11,524.52	3,100.88
	3	11,620.00		11,290.00	12,836.67				9,476.07	2,332.15
	4	13,110.00		18,330.00	14,466.67				10,729.96	3,954.21
	5	14,250.00		11,360.00	10,175.33				9,218.37	2,852.01
	6	13,210.00		12,190.00	8,141.33				8,933.70	2,563.73
	7	10,790.00		12,070.00	5,692.00				9,087.88	2,878.45
	8	9,792.00		12,190.00	7,158.50				7,901.75	2,332.65
	Avg	12,406.50		12,859.25	10,466.73				9,696.21	2,123.13
	SD	1,539.98		2,712.92	3,189.69					
Offsite	1	9,003.00		6,365.00	4,197.67	4,197.67			5,384.537	2,070.883
	2	9,171.00	9,171.00	8,046.00	5,998.33				8,187.31	1,933.838
	3	11,760.00		12,190.00	15,513.33				8,768.29	4,041.496
	Avg	9,978.00	9,171.00	8,867.00	8,569.78	4,197.67			7,645.83	1,816.574
	SD	1,545.54	0.00	2,998.03	6,080.32	0.00				

PL = post-liming.
n.s. = not sampled.

Table A6. Concentration of Mn in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Mn, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	16.07	17.75	11.81	13.33	11.71	11.50	12.38
	2	13.27	18.65	12.55	17.14	13.52	15.49	18.91	12.64
	3	11.18	11.75	31.42	21.10	0.50	11.52	0.50	11.18
	4	0.50	0.50	14.45	12.43	10.18	10.60	18.41	16.03
	5	0.50	0.50	13.66	20.21	11.05	0.50	18.20	11.62
	6	0.50	0.50	0.50	0.50	0.50	0.50	20.55	14.25
	7	12.46	11.45	32.89	19.17	12.54	10.62	0.50	11.61
	8	7.50	0.50	12.51	0.50	5.45	n.s.	0.50	11.65
	Avg	5.80	7.49	16.97	12.86	8.38	8.71	11.13	12.67
	SD	5.91	7.81	10.63	8.34	5.50	5.84	9.19	1.66
2	1	40.26	n.s.	28.63	19.97	20.72	n.s.	18.32	19.02
	2	20.91	n.s.	40.49	18.41	16.97	n.s.	22.58	21.94
	3	15.02	n.s.	18.33	14.40	19.09	n.s.	13.44	15.40
	4	22.18	n.s.	17.15	16.34	19.08	n.s.	14.57	15.92
	5	18.04	n.s.	19.15	12.49	20.46	n.s.	12.70	17.48
	6	18.66	n.s.	18.18	12.09	13.25	n.s.	15.58	11.54
	7	n.s.	n.s.	13.89	10.67	23.50	n.s.	21.31	11.93
	8	n.s.	n.s.	11.68	12.29	19.39	n.s.	14.28	19.88
	Avg	22.51		20.94	14.58	19.06		16.60	16.64
	SD	9.04		9.33	3.34	2.99		3.72	3.69
Offsite	1	0.50	n.s.	0.50	6.73	17.53	n.s.	26.81	n.s.
	2	18.74	n.s.	6.89	12.47	28.37	n.s.	12.52	n.s.
	3	17.53	n.s.	14.53	20.62	28.09	n.s.	19.53	n.s.
	Avg	12.26		7.31	13.27	24.66		19.62	
	SD	10.20		7.02	6.98	6.18		7.15	

Table A6. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Mn, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	16.63	15.47	10.52	12.76	10.83			12.40	4.28
	2	24.03	20.71	22.12	14.86	11.39			16.56	4.05
	3	0.50[a]	0.50	9.12	16.26	14.40			10.76	9.14
	4	0.50	0.50	12.04	20.12	12.39			9.90	7.11
	5	13.15	11.11	11.59	14.19	31.40			12.13	8.61
	6	10.84	11.78	15.14	11.36	19.72			8.20	7.93
	7	11.37	0.50	14.76	11.93	12.53			12.49	7.96
	8	24.72	8.96	12.16	12.12	13.50			9.17	6.99
	Avg	12.72	8.69	13.43	14.20	15.77			11.45	3.39
	SD	9.19	7.63	4.04	2.91	6.89				
2	1	22.78	n.s.	13.54	20.62	n.s.			22.65	7.71
	2	44.71	n.s.	16.94	32.34	n.s.			26.14	10.46
	3	15.82	n.s.	41.68	21.10	n.s.			19.36	8.73
	4	20.75	n.s.	17.13	24.01	n.s.			18.57	3.16
	5	22.79	n.s.	17.02	21.46	n.s.			17.95	3.57
	6	20.66	n.s.	19.46	16.34	n.s.			16.20	3.32
	7	12.43	n.s.	18.74	11.16	n.s.			15.45	5.00
	8	13.01	n.s.	22.54	14.95	n.s.			16.00	4.05
	Avg	21.62		20.88	20.25				19.23	2.70
	SD	10.21		8.79	6.42					
Offsite	1	25.67	n.s.	21.35	0.50	n.s.			12.45	11.63
	2	15.85	n.s.	15.85	15.36	n.s.			15.76	6.19
	3	34.06	n.s.	31.65	44.51	n.s.			26.31	10.12
	Avg	25.19		22.95	20.12				18.17	6.52
	SD	9.11		8.02	22.39					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg , the MDL, was substituted for calculations.

Table A7. Concentration of Mo in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Mo, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	3	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	4	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	6	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Avg	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	3	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	4	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	5	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	6	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	7	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	8	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	Avg	0.50		0.50	0.50	0.50		0.50	0.50
	SD	0.00		0.00	0.00	0.00		0.00	0.00
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	3	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	Avg	0.50		0.50	0.50	0.50		0.50	
	SD	0.00		0.00	0.00	0.00		0.00	

Table A7. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Mo, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	0.50[a]	0.50	0.01	0.50	0.50			0.46	0.136
	2	0.50	0.50	0.50	0.50	0.50			0.50	0.000
	3	0.50	0.50	0.32	0.50	0.50			0.49	0.049
	4	0.50	0.50	0.50	0.50	0.50			0.50	0.000
	5	0.50	0.50	1.34	0.50	0.50			0.56	0.233
	6	0.50	0.50	0.50	0.50	0.50			0.50	0.000
	7	0.50	0.50	0.50	0.50	0.50			0.50	0.000
	8	0.50	0.50	0.33	0.50	0.50			0.49	0.047
	Avg	0.50	0.50	0.50	0.50	0.50			0.50	0.000
	SD	0.00	0.00	0.38	0.00	0.00				
2	1	0.50	n.s.	1.08	0.50	n.s.			0.56	0.192
	2	0.50	n.s.	2.32	0.50	n.s.			0.70	0.608
	3	0.50	n.s.	1.49	0.50	n.s.			0.61	0.330
	4	0.50	n.s.	0.79	0.50	n.s.			0.53	0.097
	5	0.50	n.s.	2.06	0.50	n.s.			0.67	0.519
	6	0.50	n.s.	1.06	0.50	n.s.			0.57	0.198
	7	0.50	n.s.	0.64	0.50	n.s.			0.52	0.049
	8	0.50	n.s.	1.15	0.50	n.s.			0.58	0.230
	Avg	0.50		1.32	0.50				0.59	0.274
	SD	0.00		0.60	0.00					
Offsite	1	0.50	n.s.	0.68	0.50	n.s.			0.52	0.064
	2	0.50	n.s.	1.45	0.50	n.s.			0.62	0.335
	3	0.50	n.s.	0.66	0.50	n.s.			0.52	0.057
	Avg	0.50		0.93	0.50				0.55	0.152
	SD	0.00		0.45	0.00					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg , the MDL, was substituted for calculations.

Table A8. Concentration of V in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of V, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	15.73
	3	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	4	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	6	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Avg	0.50	0.50	0.50	0.50	0.50	0.50	0.50	2.40
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.38
2	1	20.98	n.s.	26.96	12.86	22.98	n.s.	0.50	15.57
	2	18.10	n.s.	23.02	10.65	21.18	n.s.	0.50	10.89
	3	0.50	n.s.	21.31	0.50	21.39	n.s.	0.50	10.51
	4	17.64	n.s.	19.85	0.50	20.65	n.s.	0.50	0.50
	5	18.54	n.s.	21.84	10.32	12.32	n.s.	10.79	10.76
	6	n.s.	n.s.	10.38	0.50	19.50	n.s.	0.50	11.73
	7	n.s.	n.s.	11.29	14.85	0.50	n.s.	0.50	10.05
	8	n.s.	n.s.	5.77	0.50	23.09	n.s.	15.66	9.67
	Avg	15.15		17.55	6.34	17.70		3.68	9.96
	SD	8.29		7.42	6.39	7.74		6.03	4.24
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	2	0.50	n.s.	12.53	11.57	14.03	n.s.	17.87	n.s.
	3	0.50	n.s.	0.50	14.79	15.10	n.s.	8.00	n.s.
	Avg	0.50		4.51	8.95	9.88		8.79	
	SD	0.00		6.94	7.50	8.14		8.71	

Table A8. (Concluded).

Bay	Sample ID	Sample Date/Concentration of V, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	24.08	11.18	20.02	14.23	0.50			5.69	8.61
	2	18.81	0.50	22.84	14.67	0.50			5.89	8.61
	3	22.91	12.49	19.51	12.08	0.50			5.50	8.25
	4	10.53	12.15	18.72	12.54	0.50			4.50	6.49
	5	10.54	0.50	15.28	0.50	10.37			3.17	5.20
	6	10.19	0.50	15.14	0.50	0.50			2.37	4.68
	7	0.50	0.50	15.71	0.50	0.50			1.67	4.22
	8	7.19	0.50	13.93	0.50	12.12			2.94	4.85
	Avg	13.09	4.79	17.64	6.94	3.19			3.97	5.53
	SD	8.15	5.93	3.09	6.93	5.00				
2	1	22.45	n.s.	26.45	20.69	n.s.			18.83	8.25
	2	24.54	n.s.	28.43	22.14	n.s.			17.72	8.76
	3	24.75	n.s.	28.10	22.00	n.s.			14.40	11.42
	4	25.31	n.s.	27.25	21.43	n.s.			14.85	11.13
	5	24.71	n.s.	30.86	15.79	n.s.			17.33	7.26
	6	24.84	n.s.	26.42	0.50	n.s.			11.80	10.88
	7	26.07	n.s.	28.19	0.50	n.s.			11.49	11.13
	8	21.27	n.s.	29.16	0.50	n.s.			13.20	10.78
	Avg	24.24		28.11	12.94				15.07	7.94
	SD	1.58		1.47	10.50					
Offsite	1	0.50	n.s.	10.66	0.50	n.s.			1.77	3.59
	2	16.47	n.s.	17.24	0.50	n.s.			11.34	7.05
	3	18.72	n.s.	29.97	22.25	n.s.			13.73	10.33
	Avg	11.90		19.29	7.75				8.95	5.46
	SD	9.93		9.82	12.56					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg , the MDL, was substituted for calculations.

Table A9. Concentration of Cu in soil from Fort Jackson HGR bays and offsite areas

Bay	Sample ID	Sample Date / Concentration of Cu (mg/kg)							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	11.05	10.76	26.77	10.69	0.50	10.67	17.01
	2	0.50	0.50	0.50	12.72	0.50	0.50	0.50	0.50
	3	0.50	0.50	0.50	14.04	0.50	0.50	0.50	0.50
	4	0.50	0.50	0.50	11.36	0.50	0.50	0.50	0.50
	5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	6	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Avg	0.50	1.82	1.78	8.36	1.77	0.50	1.77	2.56
	SD	0.00	3.73	3.63	9.61	3.60	0.00	3.60	5.84
2	1	45.82	n.s.	23.27	15.73	17.00	51.04	16.74	14.55
	2	14.19	n.s.	25.87	37.40	14.83	n.s.	0.05	15.65
	3	11.81	n.s.	13.34	14.61	11.98	n.s.	10.15	12.97
	4	14.46	n.s.	12.48	12.04	126.80	n.s.	0.50	24.13
	5	12.91	n.s.	12.11	10.91	13.92	n.s.	0.50	13.07
	6	10.91	n.s.	10.72	19.11	0.05	n.s.	0.50	27.82
	7	n.s.	n.s.	0.50	10.39	11.75	n.s.	0.50	0.50
	8	n.s.	n.s.	0.50	6.56	10.22	n.s.	5.39	27.34
	Avg	18.35		12.35	15.84	25.82	51.04	4.29	17.00
	SD	13.53		9.15	9.50	41.12	0.00	6.16	9.15
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	3	11.80	n.s.	0.50	11.62	18.44	n.s.	13.77	14.66
	Avg	4.27		0.50	4.21	6.48		4.92	14.66
	SD	6.52		0.00	6.42	10.36		7.66	0.00

Table A9. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Cu, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	10.16	29.32	7.92	0.50	0.50			10.49	9.44
	2	12.47	10.02	15.16	0.50	0.50			4.22	5.90
	3	16.52	0.50	25.80	0.50	0.50			4.72	8.41
	4	0.50	0.50	8.58	0.50	0.50			1.96	3.60
	5	0.50	0.50	9.70	0.50	0.50			1.21	2.55
	6	0.50	0.50	14.18	0.50	0.50			1.55	3.79
	7	0.50	0.50	8.92	0.50	0.50			1.15	2.34
	8	0.50	0.50	10.35	0.50	0.50			1.26	2.73
	Avg	5.21	5.29	12.58	0.50	0.50			3.32	3.66
	SD	6.72	10.26	5.96	0.00	0.00				
2	1	18.28	n.s.	11.83	16.92	n.s.			23.12	13.70
	2	17.60	n.s.	15.51	18.58	n.s.			17.74	9.98
	3	11.99	n.s.	17.99	32.73	n.s.			15.29	6.90
	4	14.58	n.s.	18.27	31.55	n.s.			28.31	37.91
	5	14.65	n.s.	17,360.00	39.21	n.s.			1,941.92	5,781.79
	6	13.60	n.s.	10.00	16.08	n.s.			12.09	8.67
	7	0.50	n.s.	16.04	0.50	n.s.			5.09	6.52
	8	5.42	n.s.	11.57	10.91	n.s.			9.74	8.00
	Avg	12.08		2,182.65	20.81				236.02	684.09
	SD	6.12		6,132.58	12.81					
Offsite	1	0.50	n.s.	5.37	0.50	n.s.			1.11	1.72
	2	0.50	n.s.	6.60	0.50	n.s.			1.26	2.16
	3	23.48	n.s.	19.11	17.18	n.s.			14.51	6.49
	Avg	8.16		10.36	6.06				5.62	2.94
	SD	13.27		7.60	9.63					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg , the MDL, was substituted for calculations.

Table A10. Concentration of Cr in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Cr, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	0.50	0.50	0.50	10.24	10.78	0.50	0.50
	2	10.11	12.28	12.25	0.50	11.77	0.50	0.50	12.85
	3	0.50	10.55	11.05	11.42	0.50	0.50	0.50	10.22
	4	0.50	0.50	12.27	10.44	0.50	0.50	0.50	10.65
	5	0.50	10.02	0.50	0.50	0.50	0.50	0.50	12.04
	6	0.50	11.35	0.50	0.50	0.50	0.50	0.50	11.45
	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	6.23	0.50	11.14	8.02	10.91	n.s.	0.50	11.35
	Avg	2.42	5.78	6.09	4.05	4.43	1.97	0.50	8.69
	SD	3.70	5.68	5.99	4.98	5.44	3.89	0.00	5.12
2	1	21.45	n.s.	23.98	14.49	20.28	n.s.	10.87	15.63
	2	17.47	n.s.	20.70	12.27	18.34	n.s.	0.50	14.11
	3	15.26	n.s.	18.25	12.97	17.78	n.s.	0.50	14.05
	4	21.28	n.s.	17.66	11.26	18.54	n.s.	11.60	15.87
	5	11.92	n.s.	17.44	10.95	14.56	n.s.	0.50	12.91
	6	15.72	n.s.	12.49	10.49	18.57	n.s.	0.50	14.83
	7	n.s.	n.s.	10.70	11.86	10.48	n.s.	15.54	11.38
	8	n.s.	n.s.	10.50	0.50	16.28	n.s.	10.24	10.49
	Avg	17.18		16.47	10.60	16.85		6.28	13.66
	SD	3.70		4.85	4.27	3.09		6.37	1.94
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	2	0.50	n.s.	5.30	10.26	12.00	n.s.	13.19	n.s.
	3	11.63	n.s.	0.50	15.82	20.37	n.s.	10.50	n.s.
	Avg	4.21		2.10	8.86	10.96		8.06	
	SD	6.43		2.77	7.76	9.98		6.69	

Table A10. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Cr, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	18.19	11.00	12.14	14.28	0.50[a]			6.16	6.66
	2	12.82	10.63	16.31	15.32	10.50			9.72	5.54
	3	14.30	10.92	12.85	14.53	15.17			8.69	5.89
	4	11.17	0.50	17.64	15.51	12.39			7.16	6.70
	5	14.38	11.71	13.79	12.33	13.96			7.02	6.37
	6	11.18	0.50	13.99	0.50	12.66			4.97	5.93
	7	10.71	0.50	14.47	0.50	13.00			3.32	5.42
	8	14.45	6.54	12.12	5.71	11.74			8.27	4.52
	Avg	13.40	6.54	14.16	9.83	11.24			6.85	4.35
	SD	2.49	5.24	1.96	6.56	4.56				
2	1	22.28	n.s.	18.45	21.98	n.s.			18.82	4.33
	2	23.68	n.s.	21.02	22.81	n.s.			16.77	7.18
	3	21.06	n.s.	21.54	22.84	n.s.			16.03	6.76
	4	23.18	n.s.	21.10	22.24	n.s.			18.08	4.42
	5	22.39	n.s.	20.76	20.34	n.s.			14.64	6.72
	6	23.65	n.s.	20.55	14.09	n.s.			14.54	6.66
	7	19.29	n.s.	18.91	10.59	n.s.			13.59	3.77
	8	17.19	n.s.	21.69	12.54	n.s.			12.43	6.30
	Avg	21.59		20.50	18.43				15.73	4.85
	SD	2.31		1.19	5.13					
Offsite	1	0.50	n.s.	7.36	0.50	n.s.			1.36	2.43
	2	13.40	n.s.	10.97	0.50	n.s.			8.27	5.41
	3	25.63	n.s.	27.66	26.05	n.s.			17.27	9.45
	Avg	13.18		15.33	9.02				8.96	4.36
	SD	12.57		10.83	14.75					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg, the MDL, was substituted for calculations.

Table A11. Concentration of Pb in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Pb, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	23.65	18.37	29.84	21.99	24.84	22.59	19.73	17.85
	2	18.60	22.41	21.19	15.88	19.10	13.96	13.02	21.98
	3	21.42	22.67	18.46	20.89	19.96	15.46	13.89	25.47
	4	17.16	20.11	23.24	16.93	27.69	24.78	12.99	18.66
	5	16.76	22.85	19.12	21.25	20.38	18.09	0.50[a]	31.52
	6	21.44	19.79	17.60	13.89	11.67	19.77	15.39	18.16
	7	17.55	17.62	15.33	16.93	24.94	14.85	13.20	18.79
	8	22.04	14.42	18.40	14.58	19.92	n.s.	14.36	21.42
	Avg	19.83	19.78	20.40	17.79	21.06	18.50	12.89	21.73
	SD	2.61	2.93	4.48	3.16	4.90	4.11	5.48	4.72
2	1	25.99	n.s.	26.92	21.79	24.90	n.s.	15.69	20.10
	2	25.97	n.s.	18.47	16.55	22.44	n.s.	13.13	22.15
	3	20.46	n.s.	22.97	25.38	23.86	n.s.	19.89	28.49
	4	28.53	n.s.	21.35	20.50	23.01	n.s.	18.80	26.93
	5	23.11	n.s.	22.98	19.86	23.55	n.s.	12.82	30.72
	6	19.63	n.s.	15.92	19.03	25.98	n.s.	11.50	20.58
	7	n.s.	n.s.	23.09	14.45	18.21	n.s.	17.33	18.86
	8	n.s.	n.s.	17.13	16.95	17.18	n.s.	0.50	30.88
	Avg	23.95		21.10	19.31	22.39		13.71	24.84
	SD	3.49		3.67	3.41	3.11		6.11	4.96
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	3	24.33	n.s.	21.01	23.05	41.12	n.s.	25.60	n.s.
	Avg	8.44		7.34	8.02	14.04		8.87	
	SD	13.76		11.84	13.02	23.45		14.49	

Table A11. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Pb, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	15.36	15.12	18.35	24.38	24.56			21.28	4.27
	2	15.74	16.08	17.89	24.44	23.60			18.76	3.73
	3	11.32	13.67	21.19	27.20	23.12			19.59	4.80
	4	16.48	16.71	21.88	25.86	26.85			20.72	4.67
	5	29.35	22.71	29.37	31.51	22.98			22.03	8.21
	6	20.69	25.47	30.18	28.18	25.38			20.59	5.51
	7	25.61	20.69	31.18	24.53	24.94			20.47	5.33
	8	25.56	24.20	26.59	27.57	23.42			21.04	4.76
	Avg	20.01	19.33	24.58	26.71	24.36			20.54	3.46
	SD	6.30	4.50	5.40	2.46	1.34				
2	1	26.36	n.s.	22.37	29.41	n.s.			23.73	4.17
	2	28.16	n.s.	27.83	32.66	n.s.			23.04	6.25
	3	27.04	n.s.	29.66	34.78	n.s.			25.84	4.74
	4	30.88	n.s.	29.73	27.91	n.s.			25.29	4.43
	5	31.20	n.s.	27.22	30.82	n.s.			24.70	6.06
	6	28.40	n.s.	29.26	22.48	n.s.			21.42	5.81
	7	23.09	n.s.	16.63	17.35	n.s.			18.63	3.04
	8	18.82	n.s.	29.27	25.81	n.s.			19.56	9.59
	Avg	26.74		26.50	27.65				22.91	4.42
	SD	4.11		4.67	5.67					
Offsite	1	0.50	n.s.	7.53	0.50	n.s.			1.38	2.48
	2	7.03	n.s.	13.39	0.50	n.s.			2.93	4.80
	3	47.24	n.s.	46.68	40.71	n.s.			33.72	11.24
	Avg	18.26		22.53	13.90				12.67	5.53
	SD	25.31		21.12	23.22					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg, the MDL, was substituted for calculations.

Table A12. Concentration of As in soil from Fort Jackson HGR bays and offsite areas

Bay	Sample ID	Sample Date/Concentration of As, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	3	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	4	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	6	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Avg	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	3	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	4	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	5	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	6	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	7	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	8	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	Avg	0.50		0.50	0.50	0.50		0.50	0.50
	SD	0.00		0.00	0.00	0.00		0.00	0.00
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	3	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	Avg	0.50		0.50	0.50	0.50		0.50	0.50
	SD	0.00		0.00	0.00	0.00		0.00	0.00

Table A12. (Concluded).

Bay	Sample ID	Sample Date/Concentration of As, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	0.50	0.50	0.14	0.50	0.50			0.47	0.10
	2	0.50	0.50	0.10	0.50	0.50			0.47	0.11
	3	0.50	0.50	0.05	0.50	0.50			0.47	0.13
	4	0.50	0.50	0.25	0.50	0.50			0.48	0.07
	5	0.50	0.50	0.12	0.50	0.50			0.47	0.10
	6	0.50	0.50	0.28	0.50	0.50			0.48	0.06
	7	0.50	0.50	0.17	0.50	0.50			0.47	0.09
	8	0.50	0.50	0.15	0.50	0.50			0.47	0.10
	Avg	0.50	0.50	0.16	0.50	0.50			0.47	0.09
	SD	0.00	0.00	0.08	0.00	0.00				
2	1	0.50	n.s.	0.14	0.50	n.s.			0.46	0.12
	2	0.50	n.s.	0.41	0.50	n.s.			0.49	0.03
	3	0.50	n.s.	0.59	0.50	n.s.			0.51	0.03
	4	0.50	n.s.	0.43	0.50	n.s.			0.49	0.02
	5	0.50	n.s.	0.30	0.50	n.s.			0.48	0.07
	6	0.50	n.s.	0.40	0.50	n.s.			0.49	0.04
	7	0.50	n.s.	0.15	0.50	n.s.			0.46	0.12
	8	0.50	n.s.	0.33	0.50	n.s.			0.48	0.06
	Avg	0.50		0.34	0.50				0.48	0.05
	SD	0.00		0.15	0.00					
Offsite	1	n.s.	n.s.	0.27	0.50	n.s.			0.47	0.08
	2	n.s.	n.s.	0.16	0.50	n.s.			0.46	0.12
	3	n.s.	n.s.	0.55	0.50	n.s.			0.51	0.02
	Avg			0.33	0.50				0.48	0.06
	SD			0.20	0.00					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg, the MDL, was substituted for calculations.

Table A13. Concentration of W in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of W, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	0.50	13.00	10.35	10.63	21.53	0.50	10.24
	2	0.50	12.14	0.50	0.50	25.53	15.12	0.50	17.55
	3	10.73	11.95	11.78	0.50	0.50	10.91	0.50	12.01
	4	0.50	11.72	15.68	0.50	11.40	12.43	18.61	24.46
	5	31.71	14.62	0.50	23.01	10.25	0.50	10.41	13.32
	6	0.50	10.79	0.50	0.50	0.50	15.63	0.50	0.50
	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	13.73	0.50	6.54	0.50	11.23	n.s.	7.77	10.48
	Avg	7.33	7.84	6.12	4.55	8.82	10.95	4.91	11.13
	SD	11.21	6.17	6.52	8.22	8.49	7.87	6.80	8.03
2	1	27.34	n.s.	12.86	0.50	11.64	n.s.	0.50	15.33
	2	10.29	n.s.	10.46	0.50	39.99	n.s.	0.50	15.86
	3	15.86	n.s.	0.50	11.81	0.50	n.s.	11.96	18.11
	4	14.54	n.s.	0.50	15.46	0.50	n.s.	10.26	13.04
	5	12.47	n.s.	0.50	0.50	14.54	n.s.	0.50	11.76
	6	0.50	n.s.	10.07	0.50	14.41	n.s.	0.50	14.77
	7	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	11.10
	8	n.s.	n.s.	0.50	6.33	0.50	n.s.	9.09	12.47
	Avg	13.50		4.49	4.51	10.32		4.23	14.05
	SD	8.70		5.56	6.06	13.64		5.20	2.37
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	3	0.50	n.s.	0.50	0.50	13.46	n.s.	42.36	13.52
	Avg	0.50		0.50	0.50	4.82		14.45	13.52
	SD	0.00		0.00	0.00	7.48		24.17	0.00

Table A13. (Concluded).

Bay	Sample ID	Sample Date/Concentration of W, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	0.50	0.50	15.03	11.67	12.71			8.28	7.02
	2	0.50	120.70	19.34	17.90	27.23			19.85	31.91
	3	0.50	0.50	23.52	18.32	33.02			10.36	10.18
	4	0.50	0.50	88.48	13.71	15.37			16.45	23.00
	5	34.66	18.56	96.90	22.63	13.87			22.38	24.61
	6	12.26	11.41	32.69	18.92	12.18			8.99	9.86
	7	13.72	10.84	38.48	11.54	13.01			7.04	10.98
	8	14.54	17.86	26.71	17.11	13.29			11.69	7.40
	Avg	9.65	22.61	42.64	16.47	17.59			13.12	10.34
	SD	12.00	40.34	31.82	3.87	7.95				
2	1	280.80	n.s.	27.57	12.33	n.s.			43.21	89.61
	2	14.87	n.s.	26.05	12.26	n.s.			14.53	12.33
	3	13.76	n.s.	1.30	14.66	n.s.			9.83	7.06
	4	14.61	n.s.	25.29	58.23	n.s.			16.94	17.28
	5	14.87	n.s.	22.68	14.59	n.s.			10.27	7.95
	6	13.18	n.s.	60.37	10.64	n.s.			13.88	18.46
	7	17.09	n.s.	21.22	0.50	n.s.			6.49	8.70
	8	0.50	n.s.	29.66	12.10	n.s.			8.89	9.80
	Avg	46.21		26.77	16.91				15.67	13.57
	SD	94.93		16.20	17.29					
Offsite	1	0.50	n.s.	14.27	0.50	n.s.			2.22	4.87
	2	9.09	n.s.	13.77	0.50	n.s.			3.23	5.21
	3	0.50	n.s.	38.37	18.20	n.s.			14.30	17.50
	Avg	3.36		22.14	6.40				6.58	7.82
	SD	4.96		14.06	10.22					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg, the MDL, was substituted for calculations.

Table A14. Concentration of Sb in soil from Fort Jackson HGR bays and offsite areas

Bay	Sample ID	Sample Date /Concentration of Sb, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.50[a]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	3	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	4	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	6	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	7	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Avg	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	3	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	4	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	5	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	6	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	7	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	8	n.s.	n.s.	0.50	0.50	0.50	n.s.	0.50	0.50
	Avg	0.50		0.50	0.50	0.50		0.50	0.50
	SD	0.00		0.00	0.00	0.00		0.00	0.00
Offsite	1	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	2	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	3	0.50	n.s.	0.50	0.50	0.50	n.s.	0.50	n.s.
	Avg	0.50		0.50	0.50	0.50		0.50	
	SD	0.00		0.00	0.00	0.00		0.00	

Table A14. (Concluded).

Bay	Sample ID	Sample Date /Concentration of Sb, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	0.50	0.50	1.27	0.50	0.50			0.56	0.21
	2	0.50	0.50	0.64	0.50	0.50			0.51	0.04
	3	0.50	0.50	0.24	0.50	0.50			0.48	0.07
	4	0.50	0.50	0.63	0.50	0.50			0.51	0.03
	5	0.50	0.50	0.92	0.50	0.50			0.53	0.12
	6	0.50	0.50	0.50	0.50	0.50			0.50	0.00
	7	0.50	0.50	0.50	0.50	0.50			0.50	0.00
	8	0.50	0.50	0.63	0.50	0.50			0.51	0.04
	Avg	0.50	0.50	0.67	0.50	0.50			0.51	0.05
	SD	0.00	0.00	0.31	0.00	0.00				
2	1	0.50	n.s.	0.79	0.50	n.s.			0.53	0.10
	2	0.50	n.s.	1.83	0.50	n.s.			0.65	0.44
	3	0.50	n.s.	6.52	0.50	n.s.			1.17	2.01
	4	0.50	n.s.	3.30	0.50	n.s.			0.81	0.93
	5	0.50	n.s.	0.96	0.50	n.s.			0.55	0.15
	6	0.50	n.s.	0.94	0.50	n.s.			0.55	0.15
	7	0.50	n.s.	0.50	0.50	n.s.			0.50	0.00
	8	0.50	n.s.	2.09	0.50	n.s.			0.70	0.56
	Avg	0.50		2.12	0.50				0.68	0.54
	SD	0.00		2.00	0.00					
Offsite	1	n.s.	n.s.	0.87	0.50	n.s.			0.55	0.14
	2	n.s.	n.s.	3.67	0.50	n.s.			0.95	1.20
	3	n.s.	n.s.	1.59	0.50	n.s.			0.66	0.41
	Avg			2.04	0.50				0.72	0.58
	SD			1.45	0.00					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg, the MDL, was substituted for calculations.

Table A15. Concentration of Ca in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of Ca, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	82.12	6,787.00	6,096.00	4,769.00	3,438.00	17,160.00	6,506.00	5,360.00
	2	26.34	8,930.00	7,635.00	5,623.00	5,493.00	14,490.00	5,210.00	9,680.00
	3	32.96	8,907.00	4,135.00	2,634.00	2,947.00	8,841.00	5,813.00	7,389.00
	4	20.39	7,723.00	5,706.00	4,459.00	2,896.00	18,320.00	2,162.00	7,665.00
	5	52.19	7,086.00	3,018.00	2,763.00	2,422.00	6,019.00	1,435.00	4,863.00
	6	3,829.24	8,647.00	3,604.00	1,828.00	1,415.00	26,830.00	3,489.00	8,000.00
	7	52.05	6,199.00	4,557.00	2,887.00	7,640.50	22,050.00	6,339.00	8,394.00
	8	26.89	5,866.00	3,037.50	2,946.50	2,356.00	n.s.	3,246.00	5,885.00
	Avg	515.27	7,518.13	4,723.56	3,488.69	3,575.94	16,244.29	4,275.00	7,154.50
	SD	1,339.20	1,220.63	1,634.65	1,298.73	2,019.98	7,226.73	1,952.44	1,648.71
2	1	58.41	n.s.	80.44	76.25	67.79	n.s.	73.34	46.38
	2	22.79	n.s.	84.16	76.93	55.52	n.s.	55.07	53.67
	3	15.93	n.s.	22.90	28.40	38.52	n.s.	31.83	42.22
	4	73.69	n.s.	23.13	28.43	42.89	n.s.	38.42	41.80
	5	28.44	n.s.	19.58	29.11	42.88	n.s.	48.84	49.07
	6	49.70	n.s.	20.22	21.40	47.23	n.s.	39.54	33.18
	7	n.s.	n.s.	15.93	33.76	33.28	n.s.	50.12	40.21
	8	n.s.	n.s.	31.37	23.77	31.73	n.s.	48.25	51.35
	Avg	41.49		37.22	39.76	44.98		48.18	44.74
	SD	22.64		28.19	23.03	11.95		12.66	6.70
Offsite	1	31.97	n.s.	0.50[a]	5.29	28.17	n.s.	44.89	168.20
	2	44.59	n.s.	24.50	24.35	32.73	n.s.	60.06	125.35
	3	108.10	n.s.	163.70	376.10	335.50	n.s.	3,315.00	5,008.00
	Avg	61.55		62.90	135.25	132.13		1,139.98	1,767.18
	SD	40.80		88.12	208.80	176.14		1,883.63	2,806.71

Table A15. (Concluded).

Bay	Sample ID	Sample Date/Concentration of Ca, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	6,572.00	11,220.00	8,854.00	7,298.67	13,173.33			7,485.86	4,369.43
	2	3,148.00	8,168.00	11,160.00	7,977.00	16,803.33			8,026.44	4,474.79
	3	2,608.00	9,857.00	6,770.00	7,235.33	21,603.33			6,828.66	5,332.75
	4	4,180.00	10,440.00	9,190.00	7,355.33	20,680.00			7,753.59	5,990.76
	5	16,600.00	4,712.00	7,214.00	6,613.00	19,893.33			6,360.81	5,759.50
	6	16,030.00	4,844.00	11,020.00	6,780.33	19,313.33			8,894.61	7,616.59
	7	7,061.00	13,740.00	9,071.00	7,725.00	24,090.00			9,215.81	6,949.70
	8	4,911.00	11,725.00	8,179.00	7,850.33	20,893.33			6,410.21	5,531.71
	Avg	7,638.75	9,338.25	8,932.25	7,354.38	19,556.25			77,16.56	5,205.62
	SD	5,568.63	3,230.79	1,586.03	488.06	3,301.27				
2	1	70.84	n.s.	49.07	55.04	n.s.			64.17	12.32
	2	100.10	n.s.	70.44	54.77	n.s.			63.72	22.25
	3	66.83	n.s.	56.17	61.37	n.s.			40.46	17.74
	4	146.60	n.s.	172.30	54.84	n.s.			69.12	53.64
	5	160.60	n.s.	108.00	46.51	n.s.			59.23	45.72
	6	134.30	n.s.	74.13	43.79	n.s.			51.50	35.02
	7	171.10	n.s.	144.30	57.22	n.s.			68.24	57.01
	8	244.10	n.s.	82.33	58.84	n.s.			71.47	72.20
	Avg	136.81		94.59	54.05				60.20	33.54
	SD	58.50		43.74	5.99					
Offsite	1	n.s.	n.s.	47.78	32.47	n.s.			44.91	52.58
	2	n.s.	n.s.	60.68	60.42	n.s.			54.09	32.74
	3	n.s.	n.s.	4,487.00	4,441.00	n.s.			2,279.30	2,225.04
	Avg			1,531.82	1,511.30				792.76	762.39
	SD			2,559.27	2,537.24					

PL = post-liming.
n.s. = not sampled.
[a] Below detection limits, the conservative value of 0.50 mg/kg, the MDL, was substituted for calculations.

RDX concentration in soil – initial from homogenized soil

Table A16. Lysimeter Study I RDX concentration in Fort Jackson HGR soil after homogenization (Larson et al. 2007a).

Sample ID		UV_VIS_1 (Retention Time)	UV_VIS_1 mg/L	Conversion Factor	RDX mg/kg	Avg RDX mg/kg	SD
Fort Jackson 1A	REP 1	5.22	0.3271	5	1.633	2.375	0.975
	REP 2	5.21	0.3114		1.556		
	REP 3	5.22	0.3944		1.972		
Fort Jackson 1B	REP 1	5.23	0.5191	5	2.592		
	REP 2	5.22	0.5872		2.935		
	REP 3	5.21	0.7951		3.971		
Fort Jackson 1C	REP 1	5.22	0.2462	5	1.230		
	REP 2	5.22	0.8012		4.001		
	REP 3	5.22	0.7073		3.535		
Fort Jackson 2A	REP 1	5.23	0.4101	5	2.050		
	REP 2	5.21	0.4081		2.040		
	REP 3	5.21	0.3363		1.681		
Fort Jackson 2B	REP 1	5.21	0.7236	5	3.617		
	REP 2	5.21	0.6279		3.135		
	REP 3	5.22	0.4842		2.417		
Fort Jackson 2C	REP 1	5.22	0.4221	5	2.107		
	REP 2	5.22	0.3669		1.831		
	REP 3	5.21	0.4340		2.169		
Fort Jackson 3A	REP 1	5.22	0.2160	5	1.080		
	REP 2	5.21	0.4442		2.217		
	REP 3	5.21	0.5162		2.581		
Fort Jackson 3B	REP 1	5.21	0.5084	5	2.539		
	REP 2	5.19	0.4812		2.401		
	REP 3	5.20	0.2779		1.389		
Fort Jackson 3C	REP 1	5.20	0.2182	5	1.090		
	REP 2	5.22	0.2828		1.412		
	REP 3	5.20	0.9886		4.938		

RDX concentration in soil - field samples

Table A17. Concentration of RDX in soil from Fort Jackson HGR bays and offsite areas.

Bay	Sample ID	Sample Date/Concentration of RDX, mg/kg							
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Apr-06	Apr-06 (PL)	Jul-06	Oct-06
4	1	0.05	0.10	0.05	0.04	4.15	0.12	0.16	0.02[a]
	2	0.03	0.05	0.05	0.57	2.18	0.18	0.09	0.19
	3	0.04	0.05	0.04	5.36	6.04	0.11	0.25	0.02
	4	0.13	0.05	0.04	5.12	8.63	7.27	0.56	0.02
	5	0.29	0.06	0.06	4.62	2.33	0.02	0.16	0.02
	6	0.42	0.06	0.06	12.02	8.81	6.23	0.49	0.31
	7	1.00	0.03	0.13	8.25	1.23	0.02	0.13	0.02
	8	0.72	0.03	0.08	1.44	0.32	0.09	1.60	0.78
	Dup	0.02	0.09	0.06	1.68	n.s.	n.s.	0.19	0.02
	Avg	0.30	0.05	0.06	4.68	4.21	1.75	0.43	0.17
	SD	0.35	0.02	0.03	3.94	3.29	3.10	0.48	0.26
2	1	n.s.	0.34	0.05	0.08	0.54	n.s.	2.96	0.02
	2	n.s.	5.47	0.12	0.28	0.79	n.s.	0.77	0.02
	3	n.s.	0.12	0.04	4.54	0.76	n.s.	0.11	0.02
	4	n.s.	0.05	0.04	0.77	2.55	n.s.	0.15	0.02
	5	n.s.	0.06	0.03	19.16	2.86	n.s.	0.33	0.93
	6	n.s.	0.11	0.05	9.65	2.46	n.s.	0.03	0.02
	7	n.s.	0.53	0.07	4.88	4.71	n.s.	0.37	1.12
	8	n.s.	0.21	0.03	0.15	1.37	n.s.	0.03	0.02
	Dup	n.s.	0.06	0.03	0.12	n.s.	n.s.	0.09	0.02
	Avg		0.77	0.05	4.40	2.01		0.54	0.24
	SD		1.77	0.03	6.43	1.42		0.94	0.45
Offsite	1	n.s.	0.06	0.05	n.s.	n.s.	n.s.	n.s.	n.s.
	2	n.s.	0.07	0.14	0.10	0.24	n.s.	0.30	n.s.
	3	n.s.	0.17	0.12	0.02	0.12	n.s.	1.23	n.s.
	Dup	n.s.	n.s.	0.05	n.s.	0.23	n.s.	n.s.	n.s.
	Avg		0.10	0.09	0.06	0.20		0.77	
	SD		0.06	0.05	0.06	0.07		0.66	

Table A17. (Concluded).

Bay	Sample ID	Sample Date/Concentration of RDX, mg/kg								
		Jan-07	Jan-07 (PL)	Mar-07	Jun-07	Jun-07 (PL)			Average	SD
4	1	0.06	0.60	0.04	1.36	0.22			0.54	1.15
	2	0.19	0.02	0.06	1.40	0.21			0.40	0.65
	3	0.02[a]	0.02	0.02	3.01	0.22			1.17	2.17
	4	0.07	0.02	0.02	1.51	0.64			1.85	3.05
	5	0.02	0.05	0.04	0.90	0.66			0.71	1.34
	6	1.33	0.02	0.02	0.56	0.21			2.35	4.00
	7	0.02	0.02	14.06	0.87	0.38			2.01	4.25
	8	0.02	0.06	0.05	4.78	0.15			0.78	1.32
	Dup	0.07	0.02	0.18	2.63	0.44			0.49	0.86
	Avg	0.22	0.10	1.79	1.80	0.33			1.22	1.59
	SD	0.43	0.19	4.67	1.35	0.20				
2	1	0.03	n.s.	0.12	0.39	n.s.			0.50	0.94
	2	1.01	n.s.	0.02	0.18	n.s.			0.96	1.73
	3	3.63	n.s.	0.91	0.81	n.s.			1.22	1.68
	4	0.66	n.s.	0.02	0.43	n.s.			0.52	0.81
	5	2.37	n.s.	0.02	4.41	n.s.			3.35	6.13
	6	0.02	n.s.	0.04	0.69	n.s.			1.45	3.18
	7	0.02	n.s.	0.03	0.92	n.s.			1.41	1.96
	8	0.02	n.s.	0.02	2.17	n.s.			0.45	0.78
	Dup	0.02	n.s.	0.02	2.89	n.s.			0.41	1.01
	Avg	0.87		0.13	1.43				1.16	1.37
	SD	1.30		0.29	1.43					
Offsite	1	0.08	n.s.	0.02	2.98	n.s.			0.64	1.31
	2	0.02	n.s.	0.02	3.61	n.s.			0.56	1.24
	3	0.02	n.s.	0.04	3.40	n.s.			0.64	1.19
	Dup	0.02	n.s.	1.81	0.22	n.s.			0.47	0.76
	Avg	0.04		0.47	2.55				0.53	0.85
	SD	0.03		0.89	1.57					

PL = post-liming.
n.s. = not sampled.
Dup = random duplicate sample from one sampling area.
[a] Below detection limits, the conservative value of 0.02 mg/kg , the MDL, was substituted for calculations.

RDX concentration in pore water samples

Table A18. RDX concentrations in suction lysimeter pore water from the Fort Jackson HGR bays.

Sample Date/RDX Concentration, mg/L														
Bay	Lysimeter	Oct-05	Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Mar-06	Apr-06	Apr-06 (PL)	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06
4	1	n.s.	0.082	0.103	0.095	0.071	0.079	n.s.	0.079	0.001[a]	0.001[a]	0.048	0.001[a]	0.049
	2	n.s.	0.232	n.s.	0.242	0.168	0.069	0.225	0.096	0.075	0.001[a]	0.036	0.001[a]	0.119
	3	n.s.	n.d.	0.032	0.188	0.167	0.025	0.132	0.078	0.035	0.001[a]	0.109	0.197	n.s.
	4	n.s.	0.121	n.s.	0.129	0.079	0.053	0.086	0.046	0.001a	0.001[a]	0.171	0.092	n.s.
	5	n.s.	0.032	0.047	0.046	0.020	0.012	0.001[a]	n.s.	0.033	0.001[a]	0.011	0.001[a]	n.s.
	avg		0.117	0.061	0.14	0.101	0.048	0.111	0.075	0.029	0.001	0.075	0.058	0.084
	SD		0.085	0.037	0.077	0.065	0.029	0.093	0.021	0.031	0.000	0.065	0.087	0.050
2	6	n.s.	0.602	1.225	0.584	0.343	0.087	0.249	0.255	0.001[a]	0.001[a]	0.001	0.060	n.s.
	7	n.s.	0.820	0.653	0.207	0.179	0.065	0.269	0.128	0.052	0.001[a]	0.118	n.s.	n.s.
	8	n.s.	0.959	0.870	0.373	0.271	0.073	0.419	0.250	0.128	0.001[a]	0.013	n.s.	0.042
	9	n.s.	0.642	1.061	0.912	0.564	0.210	0.841	0.403	0.127	0.001[a]	0.001[a]	0.306	n.s.
	10	n.s.	2.014	3.215	1.109	0.579	0.396	0.942	0.456	0.156	0.001[a]	0.029	0.274	n.s.
	avg		1.007	1.405	0.637	0.387	0.166	0.544	0.298	0.093	0.001	0.032	0.214	0.042
	SD		0.581	1.034	0.373	0.178	0.141	0.326	0.131	0.064	0.00	0.049	0.134	n.a.

RDX Concentration (mg/L) by Sampling Event										
Bay	Lysimeter	6-Jan-07	12- Mar-07	12- Apr-07	9-May-07	13-Jun-07	22-Jul-07	Aug-07	Sept-07	Average	SD
4	1	0.112	0.100	0.001[a]	0.087	0.024	0.048	0.0479	0.001	0.05598	0.040588
	2	0.023	0.140	0.090	0.168	0.057	0.036	0.0363	0.001	0.11456	0.094806
	3	0.116	0.239	0.049	0.109	0.001[a]	0.109	0.1088	0.1966	0.09631	0.072517
	4	0.112	0.095	0.062	0.041	0.001[a]	0.171	0.1714	0.0924	0.07796	0.054716
	5	0.129	0.060	0.030	0.075	0.0344	0.011	0.0107	0.001	0.02045	0.018149
	avg	0.098	0.127	0.046	0.096	0.0235	0.075	0.07502	0.0584	0.074117	0.040928
	SD	0.043	0.069	0.033	0.047	0.024	0.065	0.065	0.087		
2	6	0.188	0.001[a]	0.045	0.101	0.001[a]	0.001[a]	0.001	0.0602	0.3098	0.374658
	7	0.258	0.090	0.084	0.135	0.058	0.118	0.1177	n.s.	0.24914	0.271238
	8	0.278	0.173	0.160	0.191	0.089	0.013	0.0126	n.s.	0.33556	0.336983
	9	0.506	0.308	0.332	0.408	0.263	0.001[a]	0.001	0.3063	0.460764	0.37101
	10	0.527	0.367	0.238	0.280	0.184	0.029	0.0291	0.2744	0.833773	0.983049
	Avg	0.351	0.188	0.172	0.223	0.119	0.032	0.03228	0.213633	0.434945	0.439388
	SD	0.154	0.151	0.116	0.124	0.104	0.049	0.049	0.134		

n.s. = no sample available.
n.a. = not applicable.
[a] Value was below instrument detection limits. The method detection limit, 0.001 mg/L, was substituted for calculations.

Pore water characteristics

Table A19. The pH of suction lysimeter pore water from the Fort Jackson HGR bays.

Bay	Lysimeter ID	Sample Date/pH														
		Oct-05	Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Mar-06	Apr-06	Apr-06 (PL)	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06
4	1	n.d.	n.d.	n.d.	6.63	6.84	6.94	6.93	7.13	n.d.	6.68	n.d.	6.26	7.19	n.d.	n.d.
	2	n.d.	n.d.	n.d.	7.2	5.94	7.29	7.15	7.06	n.d.	5.67	7.05	n.d.	7.59	n.d.	n.d.
	3	5.97	n.d.	n.d.	7.03	6.84	7.46	7.36	7.14	n.d.	7.19	n.d.	6.4	7.41	n.d.	n.d.
	4	n.d.	n.d.	n.d.	7.09	7.06	7.44	6.47	n.d.	n.d.	6.59	n.d.	n.d.	n.d.	n.d.	n.d.
	5	n.d.	n.d.	n.d.	6.94	6.6	6.35	6.46	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Avg	5.97	n.d.	n.d.	6.98	6.66	7.10	6.87	7.11	n.d.	6.53	7.05	6.33	7.40	n.d.	n.d.
	SD	n.a.	n.d.	n.d.	0.22	0.43	0.47	0.40	0.04	n.d.	0.63	n.a.	0.10	0.20	n.d.	n.d.
2	6	5.96	n.d.	n.d.	7.03	7.19	7.16	7.31	n.d.	n.d.	7.66	n.d.	n.d.	n.d.	n.d.	n.d.
	7	6.85	n.d.	n.d.	6.89	7.29	7.48	7.5	n.d.	n.d.	7.61	5.89	n.d.	n.d.	n.d.	n.d.
	8	5.53	n.d.	n.d.	7.14	7.25	7.36	7.49	n.d.	n.d.	7.69	7.10	n.d.	7.26	n.d.	n.d.
	9	6.71	n.d.	n.d.	6.42	7.25	6.94	7.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6.88
	10	6.81	n.d.	n.d.	7.22	7.25	7.28	7.39	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Avg	6.37	n.d.	n.d.	6.94	7.25	7.24	7.34	n.d.	n.d.	7.65	6.50	n.d.	7.26	n.d.	6.88
	SD	0.59	n.d.	n.d.	0.32	0.04	0.21	0.20	n.d.	n.d.	0.04	0.86	n.d.	n.a.	n.d.	n.a.

Bay	Lysimeter ID	Sample Date/pH						
		Jan-07	Feb-07	Mar-07	Apr-07	May-07	Average	SD
4	1	7.06	6.39	6.45	6.27	6.32	6.7	0.338
	2	n.d.	7.43	7.23	7.38	7.25	7.0	0.590
	3	n.d.	7.32	7.09	7.54	7.31	7.2	0.314
	4	n.d.	7.27	7.15	7.51	7.50	7.1	0.376
	5	n.d.	n.s.	7.29	n.s.	n.s.	6.7	0.385
	Avg	7.06	7.03	7.14	7.03	6.91	7.0	0.178
	SD	n.a.	0.445	0.409	0.666	0.834		
2	6	n.d.	6.90	7.18	7.40	7.38	7.0	0.643
	7	n.d.	6.7	6.95	7.37	7.29	7.2	0.568
	8	n.d.	7.47	7.32	7.76	7.30	6.9	0.333
	9	6.74	6.81	6.89	7.34	7.42	7.1	0.498
	10	6.16	7.25	7.12	7.58	7.48	6.2	0.454
	Avg	6.45	7.03	7.09	7.49	7.37	7.0	0.485
	SD	0.41	0.323	0.174	0.177	0.080		

n.d. = not determined.
n.a. = not applicable.
n.s. = no sample available.

Table A20. Volume of suction lysimeter pore water collected from the Fort Jackson HGR bays.

Bay	Lysimeter ID	Sample Date/Volume Collected, mL														
		Oct-05	Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Mar-06	Apr-06	Apr-06 (PL)	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06
4	1	n.d.	10	20	750	50	200	50	80	n.d.	50	5	300	50	n.d.	n.d.
	2	n.d.	25	n.d.	400	75	100	50	75	n.d.	75	50	n.d.	50	n.d.	n.d.
	3	200	40	75	800	10	200	40	100	n.d.	10	n.d.	50	50	n.d.	n.d.
	4	n.d.	40	n.d.	400	50	125	75	5	n.d.	50	n.d.	n.d.	n.d.	n.d.	n.d.
	5	n.d.	50	50	800	100	200	50	n.d.	n.d.	n.d.	5	n.d.	n.d.	n.d.	n.d.
	Avg	200	33	48	630	57	165	53	65	n.d.	46	20	175	50	n.d.	n.d.
	SD	n.a.	16	28	211	33	49	13	41	n.d.	27	26	177	0	n.d.	n.d.
2	6	200	400	50	800	100	100	75	5	n.d.	10	5	n.d.	n.d.	n.d.	n.d.
	7	200	650	100	300	250	125	75	10	n.d.	10	350	n.d.	n.d.	n.d.	n.d.
	8	10	50	100	400	10	75	50	5	n.d.	10	125	n.d.	50	n.d.	n.d.
	9	200	400	10	400	100	100	10	5	n.d.	n.d.	5	n.d.	n.d.	n.d.	75
	10	200	75	200	900	75	150	100	5	n.d.	5	n.d.	n.d.	n.d.	n.d.	n.d.
	Avg	162	315	92	560	107	110	62	6	n.d.	9	121	n.d.	50	n.d.	75
	SD	85	252	71	270	88	29	34	2	n.d.	2.5	163	n.d.	n.a.	n.d.	n.a.

Bay	Lysimeter ID	Sample Date/Volume Collected, mL											
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Total	Average	SD
4	1	200	n.d.	65	65	45					1,975	123	186
	2	15	n.d.	65	65	45					1,125	80	94
	3	30	n.d.	65	65	45					1,615	108	197
	4	50	n.d.	35	35	45					960	80	105
	5	20	n.d.	10	10	40					1,390	116	222
	Avg	63	n.a.	48	48	44						96	130
	SD	78		25	25	2							
2	6	50	n.d.	40	55	n.s.					2,010	134	209
	7	50	n.d.	50	70	40					2,340	141	167
	8	50	n.d.	50	70	40					1,120	69	91
	9	100	n.d.	70	40	55					1,630	102	127
	10	100	n.d.	40	55	n.s.					2,035	136	220
	Avg	70	n.a.	50	58	45						115	99
	SD	27		12	13	9							

n.d. = not determined.
n.a. = not applicable.
n.s. = no sample available.

Table A21. Conductivity of the suction lysimeter pore water from the Fort Jackson HGR bays.

Bay	Lysimeter ID	Sample Date/Conductivity, µS/cm														
		Oct-05	Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Mar-06	Apr-06	Apr-06 (PL)	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06
4	1	n.d.	n.d.	n.d.	798	493	470	519	501	n.d.	310	n.d.	279	325	n.d.	n.d.
	2	n.d.	n.d.	n.d.	1,206	761	688	718	673	n.d.	617	519	n.d.	472	n.d.	n.d.
	3	510	n.d.	n.d.	650	419	377	351	344	n.d.	312	n.d.	343	330	n.d.	n.d.
	4	n.d.	n.d.	n.d.	1,090	739	631	767	n.d.	n.d.	734	n.d.	n.d.	n.d.	n.d.	n.d.
	5	n.d.	n.d.	n.d.	823	518	518	472	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Avg	510	n.d.	n.d.	913	586	537	565	506	n.d.	493	519	311	376	n.d.	n.d.
	SD	n.a.	n.d.	n.d.	228	154	125	174	165	n.d.	216	n.a.	45	83	n.d.	n.d.
2	6	590	n.d.	n.d.	555	389	379	391	n.d.	n.d.	379	n.d.	n.d.	n.d.	n.d.	n.d.
	7	514	n.d.	n.d.	363	284	304	249	n.d.	n.d.	210	n.d.	186	n.d.	n.d.	n.d.
	8	417	n.d.	n.d.	691	386	496	572	n.d.	n.d.	490	n.d.	495	505	n.d.	n.d.
	9	551	n.d.	n.d.	1,030	426	475	472	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	520
	10	467	n.d.	n.d.	727	426	352	410	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Avg	508	n.d.	n.d.	659	382	401	419	n.d.	n.d.	360	n.d.	341	505	n.d.	520
	SD	68	n.d.	n.d.	246	58	82	118	n.d.	n.d.	141	n.d.	218	n.a.	n.d.	n.a.

Bay	Lysimeter ID	Sample Date/Conductivity, µS/cm										
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Average	SD
4	1	292	n.s.	n.s.	n.s.	n.s.					432	165
	2	n.s.	n.s.	n.s.	n.s.	n.s.					707	224
	3	n.s.	n.s.	n.s.	n.s.	n.s.					391	110
	4	n.s.	n.s.	n.s.	n.s.	n.s.					792	175
	5	n.s.	n.s.	n.s.	n.s.	n.s.					583	162
	Avg	292	n.a.	n.a.	n.a.	n.a.					362	279
	SD	n.a.										
2	6	n.s.	n.s.	n.s.	n.s.	n.s.					447	98
	7	n.s.	n.s.	n.s.	n.s.	n.s.					300	108
	8	n.s.	n.s.	n.s.	n.s.	n.s.					502	89
	9	429	n.s.	n.s.	n.s.	n.s.					542	202
	10	300	n.s.	n.s.	n.s.	n.s.					441	137
	Avg	365	n.a.	n.a.	n.a.	n.a.					323	209
	SD	91										

n.d. = not determined.
n.a. = not applicable.
n.s. = no sample available.

Table A22. Turbidity of the suction lysimeter pore water from the Fort Jackson HGR bays.

Bay	Lysimeter ID	Sample Date/Turbidity (NTU)														
		Oct-05	Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Mar-06	Apr-06	Apr-06 (PL)	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06
4	1	n.s.	n.s.	n.s.	0	1	1	4	3	n.s.	9	n.s.	39	18	n.s.	n.s.
	2	n.s.	n.s.	n.s.	3	13	10	14	29	n.s.	45	60	n.s.	44	n.s.	n.s.
	3	28	n.s.	n.s.	5	12	35	160	56	n.s.	120	n.s.	210	140	n.s.	n.s.
	4	n.s.	n.s.	n.s.	15	31	6	90	n.s.	n.s.	310	n.s.	n.d.	n.d.	n.s.	n.s.
	5	n.s.	n.s.	n.s.	1	10	4	12	n.s.	n.s.	n.d.	n.s.	n.d.	n.d.	n.s.	n.s.
	Avg	28	n.a.	n.a.	5	13	11	56	29	n.a.	121	60	125	67	n.a.	n.a.
	SD	n.a.	n.a.	n.a.	6	11	14	68	27	n.a.	134	n.a.	121	64	n.a.	n.a.
2	6	10	n.s.	n.s.	2	11	14	70	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	7	16	n.s.	n.s.	3	1	10	21	n.s.	n.s.	n.s.	n.s.	70	n.s.	n.s.	n.s.
	8	n.s.	n.s.	n.s.	7	n.d.	80	80	n.s.	n.s.	n.s.	n.s.	310	270	n.d.	n.d.
	9	8	n.s.	n.s.	1	36	3	n.d.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	4
	10	60	n.s.	n.s.	2	36	22	33	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.d.
	Avg	24	n.a.	n.a.	3	21	26	51	n.a.	n.a.	n.a.	n.a.	190	270	n.a.	4
	SD	25	n.a.	n.a.	2	18	31	28	n.a.	n.a.	n.a.	n.a.	170	n.a.	n.a.	n.a.

Bay	Lysimeter ID	Sample Date/Turbidity (NTU)										
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Average	SD
4	1	n.s.	n.s.	n.s.	n.s.	n.s.					9	13
	2	n.s.	n.s.	n.s.	n.s.	n.s.					27	20
	3	n.s.	n.s.	n.s.	n.s.	n.s.					92	76
	4	n.s.	n.s.	n.s.	n.s.	n.s.					90	127
	5	n.s.	n.s.	n.s.	n.s.	n.s.					7	5
	Avg	n.a.	n.a	n.a	n. a	n.a					33	41
	SD											
2	6	n.s.	n.s.	n.s.	n.s.	n.s.					21	27
	7	n.s.	n.s.	n.s.	n.s.	n.s.					26	28
	8	n.s.	n.s.	n.s.	n.s.	n.s.					149	119
	9	n.s.	n.s.	n.s.	n.s.	n.s.					10	15
	10	n.s.	n.s.	n.s.	n.s.	n.s.					31	21
	Avg	n.a.	n.a	n.a	n.a	n.a					43	79
	SD											
n.s. = no sample. n.a. = not applicable. n.d. = not determined.												

Table A23. Redox potential measured from suction lysimeter pore water of the Fort Jackson HGR bays.

Bay	Lysimeter ID	Sample Date/Redox Potential, mV														
		Oct-05	Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Mar-06	Apr-06	Apr-06 (PL)	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06
4	1	n.s.	n.s.	n.s.	147	76	118	84	117	n.s.	52	n.s.	1	78	n.s.	n.s.
	2	n.s.	n.s.	n.s.	143	71	91	88	104	n.s.	31	24	n.s.	86	n.s.	n.s.
	3	20	n.s.	n.s.	126	66	89	82	101	n.s.	31	n.s.	0	76	n.s.	n.s.
	4	n.s.	n.s.	n.s.	127	64	93	118	n.s.	n.s.	18	n.s.	n.s.	n.s.	n.s.	n.s.
	5	n.s.	n.s.	n.s.	139	80	117	120	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Avg	20	n.a.	n.a.	136	71	102	98	107	n.a.	33	24	1	80	n.a.	n.a.
	SD	n.a.	n.a.	n.a.	9	7	15	19	9	n.a.	14	n.a.	1	5	n.a.	n.a.
2	6	271	n.s.	n.s.	141	96	116	105	n.s.	n.s.	36	n.s.	n.s.	n.s.	n.s.	n.s.
	7	39	n.s.	n.s.	147	107	114	96	n.s.	n.s.	24	n.s.	n.s.	n.s.	n.s.	n.s.
	8	139	n.s.	n.s.	145	124	109	96	n.s.	n.s.	27	n.s.	n.s.	63	n.s.	n.s.
	9	272	n.s.	n.s.	1	98	130	96	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	90
	10	12	n.s.	n.s.	144	98	100	101	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Avg	147	n.a.	n.a.	116	105	114	99	n.a.	n.a.	29	n.a.	n.a.	63	n.a.	90
	SD	123	n.a.	n.a.	64	12	11	4	n.a.	n.a.	6	n.a.	n.a.	n.a.	n.a.	n.a.

Bay	Lysimeter ID	Sample Date/Redox Potential, mV										
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Average	SD
4	1	147	n.s.	n.s.	n.s.	n.s.					91	47
	2	n.s.	n.s.	n.s.	n.s.	n.s.					80	39
	3	n.s.	n.s.	n.s.	n.s.	n.s.					71	40
	4	n.s.	n.s.	n.s.	n.s.	n.s.					84	44
	5	n.s.	n.s.	n.s.	n.s.	n.s.					114	25
	Avg	147	n.a.	n.a.	n.a.	n.a.					79	10
	SD	n.a.										
2	6	n.s.	n.s.	n.s.	n.s.	n.s.					128	78
	7	n.s.	n.s.	n.s.	n.s.	n.s.					101	74
	8	n.s.	n.s.	n.s.	n.s.	n.s.					95	43
	9	111	n.s.	n.s.	n.s.	n.s.					127	84
	10	114	n.s.	n.s.	n.s.	n.s.					113	63
	Avg	113	n.a.	n.a.	n.a.	n.a.					73	68
	SD	2										

n.s. = no sample.
n.a. = not applicable.

RDX concentration in surface water

Table A24. Concentration of RDX in surface water from the Fort Jackson HGR bays.

Bay	SW Collector ID	Sample Date/RDX Concentration, mg/L[a]																
		Dec-05	Dec-05 (PL)	Jan-06	Feb-06	Mar-06	Apr-06	Apr-06 (PL)	Jun-06	Jul-06	Aug-06	Sep-06	Sep-06 (PL)	Oct-06	Jan-07	Mar-07	Avg	SD
4	SW 1	n.s.	n.s.	0.0010	n.s.	0.0100	n.s.	n.s.	n.s.	n.s.	n.s.	0.0375	0.0168	n.s.	0.0425	0.0668	0.0291	0.0244
	SW 2	0.0050	0.0020	0.0030	0.0030	0.0050	0.0117	n.s.	n.s.	n.s.	0.0003	0.0036		n.s.	0.0323		0.0073	0.0099
	Avg	0.0050	0.0020	0.0020	0.0030	0.0075	0.0117				0.0003	0.0206	0.0168		0.0374	0.0668		
	SD			0.0014		0.0035						0.0240			0.0072			
2	SW 3	0.0120	n.s.	0.0150	n.s.	0.0100	n.s.	n.s.	n.s.	n.s.	0.0098	n.s.	0.0144	n.s.	n.s.		0.0122	0.0024
	SW 4	n.s.	n.s.	0.0060	n.s.	0.0060	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		0.0060	0.0000
	Avg	0.0120		0.0105		0.0080					0.0098		0.0144					
	SD			0.0064		0.0028												

n.s. = no sample.

[a] Concentration determined by SPE.

Surface water characteristics

Table A25. Surface water pH values from the Fort Jackson HGR bays.

Bay	Surface Water ID	Sample Date/pH														
		Oct-05	7-Dec-05	18-Dec-05	6-Jan-06	10-Feb-06	12-Mar-06	9-Apr-06	30-Apr-06	6-Jun-06	9-Jul-06	27-Aug-06	27-Sep-06	15-Oct-06	Nov-06	10-Dec-06
4	1	5.4	n.s.	n.s.	6.64	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	5.73	6.54	n.s.	n.s.
	2	n.s.	n.s.	4.86	6.7	n.s.	n.s.	n.s.	6.84	n.s.	5.99	n.s.	6.39	6.52	7.79	6.59
2	3	n.s.	n.s.	6.54	6.62	5.41	n.s.	n.s.	n.s.	n.s.	6.18	n.s.	6.12	6.54	n.s.	n.s.
	4	n.s.	n.s.	6.50	6.64	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Bay	Surface Water ID	Sample Date/pH										
		Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Average	SD
4	1	6.49	n.s.	7.77	n.s.	n.s.					6.38	0.76
	2	6.42	8.25	n.s.	n.s.	n.s.					6.63	0.84
2	3	n.s.	n.s.	n.s.	n.s.	n.s.					6.24	0.45
	4	n.s.	n.s.	n.s.	n.s.	n.s.					6.57	0.10

n.s. = no sample.

Table A26. Surface water volumes collected from the Fort Jackson HGR bays.

Bay	Surface Water ID	Sample Date/Volume, mL														
		2-Oct-05	7-Dec-05	18-Dec-05	6-Jan-06	10-Feb-06	12-Mar-06	9-Apr-06	30-Apr-06	6-Jun-06	9-Jul-06	27-Aug-06	27-Sep-06	15-Oct-06	Nov	10-Dec-06
4	1	1,100	n.s.	n.s.	11,000	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	10,000	900	n.d.	n.d.
	2	n.s.	900	2,000	10,000	n.s.	n.s.	n.s.	1,400	n.s.	1,000	n.s.	3,000	1,700	2,000	2,000
2	3	n.s.	n.s.	1,000	3,000	2,000	n.s.	n.s.	n.s.	n.s.	1,500	n.s.	12,000	900	n.d.	n.d.
	4	n.s.	n.s.	400	13,000	n.d.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.d.	n.d.

Bay	Surface Water ID	Sample Date/Volume, mL											
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Total volume	Average	SD
4	1	n.s.	n.s.	2,000	n.s.	n.s.					36,000	6,000	5,138
	2	n.s.	n.s.	2,000	n.s.	n.s.					29,300	3,333	3,912
2	3	n.s.	n.s.	n.s.	n.s.	n.s.					20,400	3,400	4,283
	4	n.s.	n.s.	n.s.	n.s.	n.s.					13,400	6,700	8,910

n.s. = no sample.
n.d. = not determined.

Table A27. Conductivity of surface water from the Fort Jackson HGR bays.

Bay	Surface Water ID	Sample Date/Conductivity, µS/cm														
		2-Oct-05	7-Dec-05	18-Dec-05	6-Jan-06	10-Feb-06	12-Mar-06	9-Apr-06	30-Apr-06	6-Jun-06	9-Jul-06	27-Aug-06	27-Sep-06	15-Oct-06	Nov	10-Dec-06
4	1	34	n.d.	n.d.	99	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	47	230	n.d.	n.d.
	2	n.d.	n.d.	239	83	n.d.	n.d.	n.d.	117	n.d.	171	n.d.	118	169	408	187
2	3	n.d.	n.d.	24	23	47	n.d.	n.d.	n.d.	n.d.	49	n.d.	28	46	n.d.	n.d.
	4	n.d.	n.d.	106	19	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Bay	Surface Water ID	Sample Date/Conductivity, µS/cm										
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Average	SD
4	1	153	n.d.	107	n.d.	n.d					116	67
	2	157	174	n.d.	n.d.	n.d.					171	87
2	3	n.d.	n.d.	n.d.	n.d.	n.d.					36	12
	4	n.d.	n.d.	n.d.	n.d.	n.d.					63	62

n.d. = not determined.

Table A28. Turbidity of surface water from the Fort Jackson HGR bays.

Bay	Surface Water ID	Sample Date/Surface Water Turbidity (NTU)														
		2-Oct-05	7-Dec-05	18-Dec-05	6-Jan-06	10-Feb-06	12-Mar-06	9-Apr-06	30-Apr-06	6-Jun-06	9-Jul-06	27-Aug-06	27-Sep-06	15-Oct-06	Nov	10-Dec-06
4	1	180	n.d.	n.d.	280	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	280	243	n.d.	n.d.
	2	n.d.	n.d.	47	190	n.d.	n.d.	n.d.	>999	n.d.	750	n.d.	45	149	94	16
2	3	n.d.	n.d.	193	262	700	n.d.	n.d.	n.d.	n.d.	16	n.d.	4	38	n.d.	n.d.
	4	n.d.	n.d.	189	56	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Bay	Surface Water ID	Sample Date/Surface Water Turbidity (NTU)										
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Average	SD
4	1	n.d.	n.d.	85.5	n.d.	n.d.					188	97
	2	n.d.	155	n.d.	n.d.	n.d.					174	211
2	3	n.d.	n.d.	n.d.	n.d.	n.d.					202	265
	4	n.d.	n.d.	n.d.	n.d.	n.d.					123	94

n.d. = not determined.

Table A29. Redox potential of surface water collected from the Fort Jackson HGR bays.

Bay	Surface Water ID	Sample Date/Surface Water Redox Potential, mV														
		2-Oct-05	7-Dec-05	18-Dec-05	6-Jan-06	10-Feb-06	12-Mar-06	9-Apr-06	30-Apr-06	6-Jun-06	9-Jul-06	27-Aug-06	27-Sep-06	15-Oct-06	Nov-06	10-Dec-06
4	1	229	n.d.	n.d.	96	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	114	73	n.d.	n.d.
	2	n.d.	n.d.	128	127	n.d.	n.d.	n.d.	81	n.d.	64	n.d.	16	51	66	83
2	3	n.d.	n.d.	160	103	126	n.d.	n.d.	n.d.	n.d.	57	n.d.	103	120	n.d.	n.d.
	4	n.d.	n.d.	167	114	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Bay	Surface Water ID	Sample Date/Surface Water Redox Potential, mV										
		Jan-07	Feb-07	Mar-07	Apr-07	May-07					Average	SD
4	1	83	n.d.	52	n.d.	n.d.					99	62
	2	64	-74	n.d.	n.d.	n.d.					71	60
2	3	n.d.	n.d.	n.d.	n.d.	n.d.					112	34
	4	n.d.	n.d.	n.d.	n.d.	n.d.					141	37

n.d. = not determined.

Metal concentrations in pore water and surface water

Table A30. Soluble Ni concentrations in pore water and surface water from the Fort Jackson HGR bays.

Bay	Sample ID	Sample Date/Ni Concentration, mg/L											
		7-Dec-05	18-Dec-05	30-Dec-05	Jan-06	Mar-06	Apr-06	Jun-06	Jul-06	Sep-06	Oct-06	Nov-06	Dec-06
4	L1	0.30	0.56	n.s.	0.11	0.13	n.s.	0.11	0.07	0.13	0.17	n.s.	n.s.
	L2	0.48	n.s.	n.s.	0.12	0.07	0.04	0.06	0.06	n.s.	0.03	n.s.	n.s.
	L3	0.12	0.09	n.s.	0.03	0.05	0.07	0.06	0.10	0.11	n.s.	n.s.	n.s.
	L4	1.49	n.s.	n.s.	0.04	0.00	0.04	0.04	0.07	n.s.	n.s.	n.s.	n.s.
	L5	0.32	0.37	n.s.	0.09	0.10	0.09	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	S1[a]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW1[b]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.01	n.s.	n.s.
	SW2	0.06	<0.05	0.01	0.01	n.s.	n.s.	0.01	n.s.	n.s.	0.00	n.s.	n.s.
2	L6	0.51	0.22	n.s.	0.08	0.19	0.13	n.s.	0.20	n.s.	n.s.	n.s.	n.s.
	L7	0.55	0.35	n.s.	0.10	0.32	0.14	0.13	0.16	n.s.	n.s.	n.s.	n.s.
	L8	2.94	0.19	n.s.	0.07	0.16	0.10	0.14	0.19	n.s.	0.22	n.s.	n.s.
	L9	1.22	n.s.	n.s.	0.29	0.32	0.21	0.21	n.s.	n.s.	n.s.	n.s.	n.s.
	L10	0.88	0.10	n.s.	0.04	0.07	0.06	n.s.	0.03	n.s.	n.s.	n.s.	n.s.
	S2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW3	n.s.	n.s.	0.01	n.s.	0.03	n.s.	n.s.	n.s.	n.s.	0.02	n.s.	n.s.
	SW4	n.s.	n.s.	0.59	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Bay	Sample ID	Sample Date/Ni Concentration, mg/L											
		Jan-07	Feb-07	Mar-07								Average	SD
4	L1	0.128	0.101	0.127								0.176	0.142
	L2	0.256	0.050	0.050								0.124	0.139
	L3	0.061	0.074	0.059								0.077	0.024
	L4	0.050	0.071	0.050								0.215	0.479
	L5	0.416	0.461	0.451								0.287	0.167
	S1	n.s.	n.s.	n.s.								n.s.	n.a.
	SW1	0.050	n.s.	n.s.								0.079	0.041
	SW2	0.050	n.s.	n.s.								0.054	0.033
2	L6	0.179	0.200	0.131								0.205	0.123
	L7	0.056	0.069	0.057								0.194	0.162
	L8	0.155	0.173	0.124								0.405	0.885
	L9	0.189	0.111	0.050								0.324	0.371
	L10	0.164	0.106	0.050								0.171	0.269
	S2	n.s.	n.s.	n.s.								n.s.	n.a.
	SW3	n.s.	n.s.	n.s.								0.031	0.019
	SW4	n.s.	n.s.	n.s.								n.s.	n.a.

n.s. = no sample.
n.a = not applicable.
[a] S = sump.
[b] SW = surface water.

Table A31. Soluble Zn concentrations in pore water and surface water from the Fort Jackson HGR bays.

Bay	Sample ID	Sample Date/Zn Concentration, mg/L											
		7-Dec-05	18-Dec-05	30-Dec-05	6-Jan-06	12-Mar-06	9-Apr-06	4-Jun-06	9-Jul-06	27-Sep-06	15-Oct-06	Nov-06	Dec-06
4	L1	0.25	1.09	n.s.	2.06	1.86	n.s.	0.79	0.24	0.14	0.29	n.s.	n.s.
	L2	0.13	n.s.	n.s.	0.12	0.36	<0.05	<0.05	0.06	n.s.	<0.05	n.s.	n.s.
	L3	0.98	0.53	n.s.	0.14	0.26	0.15	0.06	0.06	0.13	n.s.	n.s.	n.s.
	L4	9.15	n.s.	n.s.	0.32	<0.05	0.05	<0.05	0.07	n.s.	n.s.	n.s.	n.s.
	L5	1.17	1.48	n.s.	0.82	1.15	0.73	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	S1[a]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW1[b]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.07	n.s.	n.s.
	SW2	4.17	1.49	1.51	1.79	n.s.	n.s.	<0.05	n.s.	n.s.	<0.05	n.s.	n.s.
2	6	0.27	0.28	n.s.	0.06	0.56	0.35	n.s.	<0.05	n.s.	n.s.	n.s.	n.s.
	7	0.25	0.24	n.s.	0.09	0.28	0.16	0.11	<0.05	n.s.	n.s.	n.s.	n.s.
	8	0.20	0.07	n.s.	<0.05[c]	0.10	<0.05	<0.05	<0.05	n.s.	0.15	n.s.	n.s.
	9	1.50	n.s.	n.s.	9.22	5.37	3.55	1.68	n.s.	n.s.	n.s.	n.s.	n.s.
	10	0.29	0.16	n.s.	0.15	0.33	0.07	n.s.	<0.05	n.s.	n.s.	n.s.	n.s.
	S2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW3	n.s.	n.s.	2.42	n.s.	1.84	n.s.	n.s.	n.s.	n.s.	3.85	n.s.	n.s.
	SW4	n.s.	n.s.	2.97	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Bay	Sample ID	Sample Date/Zn Concentration, mg/L									
		Jan-07	Feb-07	Mar-07						Average	SD
4	L1	0.331	1.036	0.959						0.822	0.664
	L2	0.349	0.052	0.050						0.127	0.123
	L3	0.271	0.250	0.228						0.277	0.278
	L4	0.257	0.299	0.260						1.168	2.994
	L5	0.314	0.223	0.050						0.741	0.448
	S1	n.s.	n.s.	n.s.						n.s.	n.a.
	SW1	0.058	n.s.	n.s.						0.066	0.011
	SW2	0.050	n.s.	n.s.						1.303	1.487
2	6	0.213	0.158	0.050						0.205	0.168
	7	0.098	0.129	0.060						0.146	0.083
	8	0.124	0.191	0.088						0.102	0.058
	9	1.153	0.131	0.050						2.832	3.132
	10	0.082	0.034	0.050						0.135	0.107
	S2	n.s.	n.s.	n.s.						n.s.	n.a.
	SW3	n.s.	n.s.	n.s.						2.703	1.032
	SW4	n.s.	n.s.	n.s.						2.969	n.a.

n.s. = no sample.
n.a. = not applicable.
[a] S = sump.
[b] SW = surface water.
[c] The reporting limit for metals was used for statistical purposes when the concentration was below the machine detection value.

Table A32. Soluble Fe concentrations in pore water and surface water from the Fort Jackson HGR bays.

Bay	Sample ID	Sample Date/Fe Concentration, mg/L											
		7-Dec-05	18-Dec-05	30-Dec-05	6-Jan-06	12-Mar-06	9-Apr-06	4-Jun-06	9-Jul-06	27-Sep-06	15-Oct-06	Nov-06	Dec-06
4	L1	<0.05	<0.05	n.s.	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	0.33	n.s.	n.s.
	L2	<0.05	n.s.	n.s.	<0.05	<0.05	<0.05	<0.05	<0.05	n.s.	0.25	n.s.	n.s.
	L3	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	0.08	0.10	2.22	n.s.	n.s.	n.s.
	L4	<0.05	n.s.	n.s.	<0.05	<0.05	<0.05	0.09	0.24	n.s.	n.s.	n.s.	n.s.
	L5	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	S1[a]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW1[b]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.33	n.s.	n.s.
	SW2	<0.05	<0.05	<0.05	<0.05	n.s.	n.s.	<0.05	n.s.	n.s.	<0.05	n.s.	n.s.
2	6	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	n.s.	0.15	n.s.	n.s.	n.s.	n.s.
	7	<0.05	<0.05	n.s.	<0.05	<0.05	0.06	0.05	0.06	n.s.	n.s.	n.s.	n.s.
	8	<0.05	<0.05	n.s.	<0.05	<0.05	0.06	0.12	0.09	n.s.	12.66	n.s.	n.s.
	9	<0.05	n.s.	n.s.	<0.05	<0.05	<0.05	<0.05	n.s.	n.s.	n.s.	n.s.	n.s.
	10	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	n.s.	<0.05	n.s.	n.s.	n.s.	n.s.
	S2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW3	n.s.	n.s.	<0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	<0.05	n.s.	n.s.
	SW4	n.s.	n.s.	<0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Bay	Sample ID	Sample Date/Fe Concentration, mg/L										
		Jan-07	Feb-07	Mar-07							Average	SD
4	L1	0.050	0.204	n.d.							0.090	0.093
	L2	0.050	0.715	0.050							0.137	0.213
	L3	3.374	5.388	5.400							1.528	2.210
	L4	5.924	7.256	8.039							2.417	3.533
	L5	0.050	0.305	0.050							0.082	0.090
	S1	n.s.	n.s.	n.s.							n.s.	n.a.
	SW1	0.482	n.s.	n.s.							0.407	0.107
	SW2	0.280	n.s.	n.s.							0.083	0.087
2	6	8.705	7.403	3.311							2.202	3.499
	7	1.700	2.969	1.585							0.663	1.046
	8	19.800	22.110	13.900							6.267	8.957
	9	0.050	0.192	0.072							0.070	0.050
	10	0.838	0.781	0.719							0.293	0.366
	S2	n.s.	n.s.	n.s.							n.s.	n.a.
	SW3	n.s.	n.s.	n.s.							0.050	n.a.
	SW4	n.s.	n.s.	n.s.							0.050	n.a.

n.s. = no sample.
n.d. = not determined.
n.a. = not applicable.
[a] S = sump.
[b] SW = surface water.

Table A33. Soluble Mn concentrations in pore water and surface water from the Fort Jackson HGR bays.

Bay	Sample ID	Sample Data/Mn Concentration, mg/L											
		7-Dec-05	18-Dec-05	30-Dec-05	6-Jan-06	12-Mar-06	9-Apr-06	4-Jun-06	9-Jul-06	27-Sep-06	15-Oct-06	Nov-06	Dec-06
4	L1	0.27	0.72	n.s.	0.23	0.22	n.s.	0.23	0.13	0.20	0.21	n.s.	n.s.
	L2	1.40	n.s.	n.s.	0.25	0.16	0.13	0.14	0.18	n.s.	<0.05	n.s.	n.s.
	L3	0.43	0.17	n.s.	0.06	0.11	0.15	0.17	0.18	0.05	n.s.	n.s.	n.s.
	L4	8.53	n.s.	n.s.	0.16	<0.05	0.10	0.13	0.14	n.s.	n.s.	n.s.	n.s.
	L5	1.23	0.82	n.s.	0.20	0.25	0.22	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	S1[a]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW1[b]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	<0.05	n.s.	n.s.
	SW2	0.16	<0.05	<0.05	<0.05	n.s.	n.s.	<0.05	n.s.	n.s.	<0.05	n.s.	n.s.
2	6	1.51	0.89	n.s.	0.20	0.42	0.38	n.s.	0.39	n.s.	n.s.	n.s.	n.s.
	7	1.51	0.48	n.s.	0.18	0.37	0.32	0.35	0.31	n.s.	n.s.	n.s.	n.s.
	8	1.11	0.28	n.s.	0.13	0.27	0.21	0.23	0.22	n.s.	0.10	n.s.	n.s.
	9	1.74	n.s.	n.s.	0.34	0.37	0.27	0.24	n.s.	n.s.	n.s.	n.s.	n.s.
	10	0.77	0.24	n.s.	0.11	0.16	0.20	n.s.	0.03	n.s.	n.s.	n.s.	n.s.
	S2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW3	n.s.	n.s.	0.05	n.s.	0.07	n.s.	n.s.	n.s.	n.s.	<0.05	n.s.	n.s.
	SW4	n.s.	n.s.	0.08	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Bay	Sample ID	Sample Data/Mn Concentration, mg/L										
		Jan-07	Feb-07	Mar-07							Average	SD
4	L1	0.112	0.087	0.071							0.226	0.177
	L2	0.202	0.050	0.050							0.260	0.406
	L3	0.050	0.050	0.050							0.134	0.112
	L4	0.074	0.086	0.057							1.037	2.811
	L5	0.300	0.282	0.139							0.430	0.385
	S1	n.s.	n.s.	n.s.							n.s.	n.s.
	SW1	0.050	n.s.	n.s.							0.050	n.a.
	SW2	0.050	n.s.	n.s.							0.065	0.041
2	6	0.166	0.147	0.056							0.462	0.462
	7	0.050	0.050	0.050							0.367	0.428
	8	0.082	0.090	0.050							0.252	0.294
	9	0.139	0.060	0.050							0.400	0.552
	10	0.115	0.095	0.050							0.200	0.224
	S2	n.s.	n.s.	n.s.							n.s.	n.s.
	SW3	n.s.	n.s.	n.s.							0.057	0.012
	SW4	n.s.	n.s.	n.s.							0.076	n.a.

n.s. = no sample.
n.a. = not applicable.
[a] S = sump.
[b] SW = surface water.

Table A34. Soluble Mo concentrations in pore water and surface water from the Fort Jackson HGR bays.

Bay	Sample ID	Sample Data/Mo Concentration, mg/L											
		7-Dec-05	18-Dec-05	30-Dec-05	6-Jan-06	12-Mar-06	9-Apr-06	4-Jun-06	9-Jul-06	27-Sep-06	15-Oct-06	Nov-06	Dec-06
4	L1	<0.05	<0.05	n.s.	0.05	0.07	n.s.	<0.05	0.12	0.07	0.07	n.s.	n.s.
	L2	0.24	n.s.	n.s.	0.06	0.07	0.07	0.10	0.10	n.s.	0.10	n.s.	n.s.
	L3	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	<0.05	0.05	0.07	n.s.	n.s.	n.s.
	L4	0.29	n.s.	n.s.	0.07	<0.05	0.06	0.08	0.08	n.s.	n.s.	n.s.	n.s.
	L5	0.05	<0.05	n.s.	<0.05	<0.05	<0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	S1[a]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW1[b]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	<0.05	n.s.	n.s.
	SW2	<0.05	<0.05	<0.05	<0.05	n.s.	n.s.	<0.05	n.s.	n.s.	<0.05.	n.s.	n.s.
2	6	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	n.s.	0.05	n.s.	n.s.	n.s.	n.s.
	7	<0.05	<0.05	n.s.	<0.05	<0.05	<0.05	<0.05	0.06	n.s.	n.s.	n.s.	n.s.
	8	<0.05	0.12	n.s.	0.09	0.14	0.14	0.30	0.33	n.s.	0.37	n.s.	n.s.
	9	<0.05	n.s.	n.s.	<0.05	<0.05	<0.05	<0.05	n.s.	n.s.	n.s.	n.s.	n.s.
	10	0.08	0.08	n.s.	<0.05	0.06	0.06	n.s.	<0.05	n.s.	n.s.	n.s.	n.s.
	S2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW3	n.s.	n.s.	<0.05	n.s.	0.00	n.s.	n.s.	n.s.	n.s.	<0.05	n.s.	n.s.
	SW4	n.s.	n.s.	<0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Bay	Sample ID	Sample Data/Mo Concentration, mg/L										
		Jan-07	Feb-07	Mar-07	Apr-07						Average	SD
4	L1	0.359	0.051	n.s.	0.050						0.089	0.091
	L2	0.050	0.065	n.s.	0.078						0.093	0.055
	L3	0.050	0.059	n.s.	0.070						0.055	0.008
	L4	0.059	0.056	n.s.	0.050						0.089	0.077
	L5	0.053	0.068	n.s.	0.065						0.055	0.008
	S1	n.s.	n.s.	n.s.	n.s.						n.s.	n.s.
	SW1	n.s.	n.s.	n.s.	n.s.						n.s.	n.s.
	SW2	n.s.	n.s.	n.s.	n.s.						0.050	
2	6	0.084	0.105	n.s.	0.056						0.060	0.020
	7	0.085	0.112	n.s.	0.094						0.065	0.023
	8	0.210	0.197	n.s.	0.113						0.188	0.105
	9	0.050	0.075	n.s.	0.133						0.064	0.029
	10	0.120	0.114	n.s.	0.064						0.074	0.026
	S2	n.s.	n.s.	n.s.	n.s.						n.s.	
	SW3	n.s.	n.s.	n.s.	n.s.						0.05	0
	SW4	n.s.	n.s.	n.s.	n.s.						0.05	n.a.

n.s. = no sample.
n.a. = not applicable.
[a] S = sump.
[b] SW = surface water.

Table A35. Soluble Ca concentrations in pore water and surface water from the Fort Jackson HGR bays

Bay	Sample ID	Sample Data/Ca Concentration, mg/L											
		7-Dec-05	18-Dec-05	30-Dec-05	6-Jan-06	12-Mar-06	9-Apr-06	4-Jun-06	9-Jul-06	27-Sep-06	15-Oct-06	Nov-06	Dec-06
4	L1	n.s.	12.14	n.s.	7.65	5.95	n.s.	2.16	1.06	0.94	0.89	n.s.	n.s.
	L2	n.s.	n.s.	n.s.	5.26	2.09	n.s.	0.83	0.89	n.s.	1.13	n.s.	n.s.
	L3	n.s.	5.33	n.s.	1.64	1.86	n.s.	0.59	1.11	0.65	n.s.	n.s.	n.s.
	L4	n.s.	n.s.	n.s.	5.88	<0.05	n.s.	0.98	1.83	n.s.	n.s.	n.s.	n.s.
	L5	n.s.	10.52	n.s.	2.73	2.48	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	S1[a]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW1[b]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	36.91	n.s.	n.s.
	SW2	n.s.	2.92	1.84	2.03	n.s.	n.s.	20.03	n.s.	n.s.	26.30	n.s.	n.s.
2	6	n.s.	14.46	n.s.	2.68	5.25	n.s.	n.s.	3.78	n.s.	n.s.	n.s.	n.s.
	7	n.s.	7.94	n.s.	3.06	3.89	n.s.	1.36	1.23	n.s.	n.s.	n.s.	n.s.
	8	n.s.	8.36	n.s.	4.09	3.89	n.s.	1.61	2.51	n.s.	2.12	n.s.	n.s.
	9	n.s.	n.s.	n.s.	11.24	7.65	n.s.	4.51	n.s.	n.s.	n.s.	n.s.	n.s.
	10	n.s.	10.34	n.s.	4.32	3.38	n.s.	n.s.	0.88	n.s.	n.s.	n.s.	n.s.
	S2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	SW3	n.s.	n.s.	0.98	n.s.	0.79	n.s.	n.s.	n.s.	n.s.	2.23	n.s.	n.s.
	SW4	n.s.	n.s.	2.35	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Bay	Sample ID	Sample Data/Ca Concentration, mg/L										
		Jan-07	Feb-07	Mar-07	Apr-07						Average	SD
4	L1	1.01	2.35	n.s.	2.42						3.66	3.76
	L2	0.81	0.23	n.s.	0.98						1.53	1.593
	L3	1.03	0.68	n.s.	1.48						1.60	1.47
	L4	0.38	0.95	n.s.	2.05						2.01	1.99
	L5	0.74	1.07	n.s.	4.55						3.68	3.615
	S1	n.s.	n.s.	n.s.	n.s.						n.s.	
	SW1	n.s.	n.s.	n.s.	n.s.						36.91	0
	SW2	n.s.	n.s.	n.s.	n.s.						10.62	11.669
2	6	1.22	1.39	n.s.	2.62						4.49	4.611
	7	0.68	0.82	n.s.	2.50						2.69	2.407
	8	1.06	1.49	n.s.	2.89						3.11	2.2247
	9	2.29	3.87	n.s.	2.96						5.42	3.407
	10	2.10	2.38	n.s.	2.30						3.77	3.089
	S2	n.s.	n.s.	n.s.	n.s.						n.s.	
	SW3	n.s.	n.s.	n.s.	n.s.						1.33	0.781
	SW4	n.s.	n.s.	n.s.	n.s.						2.35	0

n.s. = no sample.
[a] S = sump.
[b] SW = surface water.

Meteorological data

Complete meteorological data can be obtained from the report authors by request to

Email: EL-Inquiry@erdc.usace.army.mil

Mail: U.S. Army Engineer Research and Development Center
ATTN: Environmental Laboratory/Technical Director,
Environmental Quality Technology R&D Program
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

Appendix B: Air Sampling Data Validation – Galson Laboratory

Memorandum

Date: March 7, 2006
To: Todd Wilson/Columbia
From: Harold McDaniel/Florence
Subject: Data Validation
Ft Jackson ESTCP Project
09090-083-100

Limited validation was performed on two data packages from Galson Laboratories (Galson) of East Syracuse, New York for air sampling. The samples were collected January 10 and 27, 2006 at the Ft Jackson ESTCP site in Columbia, South Carolina. The data was reviewed for conformance to the requirements of National Institute of Occupational Safety and Health (NIOSH) and the American Industrial Hygiene Association (AIHA). Galson processed and reported the results under the sample delivery groups (SDG) L128026 and L128720. The following analytical methods were requested on the chains-of-custody (COCs) and/or by the project manager:

- Method 7300 – Modified NIOSH method for calcium analysis by Inductively Coupled Plasma /Mass Spectrometry (ICP/MS).

Data were validated using the "USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review" (October 1999) modified for method specific requirements.

Review Elements

Sample data were reviewed for the following parameters:

- Agreement of analyses conducted with chain-of-custody (COC) requests,
- Holding times/sample preservation,
- Calibrations,
- Method blanks,
- Laboratory control sample (LCS/LCSD) results,
- Matrix spike/matrix spike duplicate (MS/MSD) results,
- Serial dilutions, and
- Field duplicate results.

Samples

ENSR collected the following samples included in this review:

SDG L128026

SAMPLE ID	LAB ID	SAMPLE ID	LAB ID
BAY 4 02	L128026-1	BAY 2 02	L128026-3
BAY 4 02D	L128026-2	LAB BLANK	L128026-4

SDG L128720

SAMPLE ID	LAB ID	SAMPLE ID	LAB ID
BAY 4 03 MS	L128720-1	BAY 2 03	L128720-3
BAY 4 03 MSD	L128720-2		

Analytical Results

No sample data was qualified with a J (estimated), R (rejected) or U (non-detect due to blank contamination or due to nonconformance with QC criteria).

It was noted that during the preparation of sample BAY 2 02 in SDG L128026, the backup pad was digested together with the filter due to particulate and discoloration on the backup pad. The backup pads for other samples in this delivery group showed no noticeable particulate and were digested separately to determine calcium background. The average background from the determination was used to correct the total µg result for sample BAY 2 02. No validation action was taken due to this laboratory adjustment.

DISCUSSION

Agreement of Analyses Conducted with COC Requests

Sample reports were checked to verify that the results corresponded to analytical requests as designated on the COC. No discrepancies were noted.

Holding Times and Preservation

Calcium samples were analyzed within the 180-day hold time. It was noted that Galson needed to re-analyze sample BAY 2 02 in SDG L128026 in order to bring the

concentration within the linear range for the instrument. The sample was re-analyzed within the hold time; therefore no validation action was required.

Initial and Continuing Calibrations

Initial and continuing calibration (ICV/CCV) verification data were within the acceptable 90-110% QC criteria. The detection limit standard (DLS) was within the QC limits of 80-120%.

Blanks

No target analytes were detected at concentrations exceeding reporting limits in the method blanks (MB), initial or continuing calibration blanks (ICB/CCB).

Laboratory Control Samples

Laboratory control sample (LCS) and LCS duplicate (LCSD) analyte recoveries were within the acceptable QC limits of 75-125%.

Matrix Spike/Matrix Spike Duplicates

The matrix spike/matrix spike duplicate (MS/MSD) recoveries and precision were acceptable for all calcium analyses.

Serial Dilution

The serial dilutions for calcium analysis were within the +/- 10% acceptable limit for all analyses.

Field Duplicates

Table B1 lists the field duplicate precision. All samples had precision results that were within acceptable QC limits.

Table B1. Field Precision

Field Identification	Analyte	Sample Concentration	Duplicate Concentration	RPD	Qualification
BAY 4 02/BAY 4 02D	Calcium	<0.01	<0.01	NC	A
BAY 4 03 MS/BAY 4 03 MSD	Calcium	<0.01	0.015	NC	A

RPD = Relative Percent Difference (Sample — Duplicate) *200/(Sample + Duplicate)

A – Acceptable

J – The reported concentration or quantitation limit is approximate due to inability to meet one or more quality control criteria.

NC – Not calculable

Appendix C: Soldier/Range Cadre Exposure Risk Analysis of Lime vs. RDX during HGR Training

CSTE-DTC-AT-SL-E 24 Oct 07

MEMORANDUM FOR RECORD

SUBJECT: Calcium Hydroxide Exposure Risk Review

1. Gene L. Fabian (ATC METDC) and Greg Zynda (ATSS support contractor) met with Derrick Butler (ATC Safety) on 19 Jun 2007 to discuss potential exposure risks that may result from calcium hydroxide application on hand grenade training ranges, as well as potential exposure risks during maintenance and use of the range.

2. The purpose of the application of calcium hydroxide on grenade range soils is to elevate the pH of the soil to between 10.5 and 12.5. In this pH range, the explosive residues in the soil that are deposited during training activities will degrade via a hydrolysis reaction. This reaction results in the mineralization of the explosive components to base hydrogen and carbon compounds. The use of calcium hydroxide is being investigated by ATC to provide a mean's. of managing explosives residues on training ranges to limit their environmental impacts and to minimize future clean up costs.

3. The 3 possible exposure scenarios discussed included calcium hydroxide application, range maintenance activities, and range use. Each scenario is described and exposure risks discussed below:

3.1 Calcium hydroxide is topically applied with a drop spreader that is pulled behind an all terrain vehicle (ATV). After topical application, the ATV is used to pull a disc attachment to mix the calcium hydroxide to a 6 inch depth in the soil. ATC had intended to perform personnel breathing zone monitoring during the last application round, but there was a miscommunication between ATC and the project principle investigator (PI), Engineer Research and Development Center-Environmental Laboratory (ERDC-EL) concerning the schedule for the field activities at Fort Jackson. As a result, no breathing zone monitoring was performed. Based on a description of ATC personnel observations of dust formation during earlier application rounds potential exposure concerns were identified. There could be dermal and inhalation hazards to the personnel applying the calcium hydroxide to the range during the spreading activities. It is advised that the personnel wear a HEPA filter respiratory mask and gloves to minimize dermal and inhalation risk. If skin is exposed during application, then it should be washed shortly after field work is completed to minimize dermal contact. For additional exposure reduction, clothing and hooding that covers the skin, such as Tyvek, may be worn

especially if washing exposed areas shortly after field work cannot be performed. To further limit exposure, calcium hydroxide should not be applied in windy conditions or during extremely dry and hot conditions.

3.2 Air monitoring data was collected at the throwing pit during range use. The air monitoring results for the hand grenade training range at Fort Jackson's Remagen Range indicate that the risks associated with calcium hydroxide applied to the impact areas are very low to the soldiers and cadre using the range during normal training operations. The calcium concentrations detected in air during training operations in 2005/2006 were either very low or below the detection limits. These results indicate that a detailed risk assessment is not warranted.

3.3 Typical range maintenance activities consist of filling in the craters formed by range use and/or grading the cratered area with a tractor. Based on visual observations of maintenance activities, dust generation from the amended soils was not significant enough to result in inhalation or dermal contact exposure. It is suggested that these maintenance activities not be performed in extremely windy or extremely dry and hot conditions. If maintenance activities must be performed during these conditions, then the use of the HEPA filtered respiratory mask and gloves is recommended to minimize potential dermal and inhalation risk.

4. ATC Safety suggested that breathing zone data be collected during calcium hydroxide application on the range. ATC will collect this data during an upcoming field demonstration of the use of calcium hydroxide on open detonation ranges to manage explosive constituents. This demonstration will be performed at ATC with an expected start date in Jun 2008.

5. The point of contact for this memorandum for record is Gene L. Fabian at 3-7421 or Greg Zynda at 3-7698.

Derrick O. Butler

DERRICK BUTLER
Safety and Occupational Health Manager,
Occupational & System Safety Team,
Safety Division, Command Staff

Gene L Fabian

GENE FABIAN
Test Director, S/L Directorate, METDC Division

Appendix D: Standard Procedure for Determination of the Lime Requirement of Different Soils for the Alkaline Hydrolysis of Explosive Compounds and Metals

The method is reproduced here from Davis et al. (2006). If sufficient laboratory facilities and supplies are available and/or there is a need to determine the lime dose required for your range soil other than through the use of the RDX Test Kit, the following procedure can be used.

Materials

- Stir plates – 8
- Stir bars to fit a 50-mL beaker – 8
- Weighing paper and spatula
- pH buffers, 4 and 10
- Soil to be tested (approximately 200 g)
- 50-ml glass beakers – 8
- Balance with an accuracy to 3 decimal places
- pH meter and electrode
- 20-mL pipettes and pipettor

Chemicals

- Water (tap or rainwater)
- Powdered hydrated lime ($Ca(OH)_2$)

Method

1. Add stir bars to the beakers and label the beakers according to the lime content to be added, listed in Table E-1. There will be one beaker with no lime added, the pH control.
2. Calibrate the pH meter using a two-point calibration of pH 4 and 10.
3. Weigh out 20 g of the test soil for each beaker.
4. Weigh out the appropriate lime dose for each beaker (Table D-1) and add it to the soil.
5. Add 20-mL water to each beaker and start the slurry gently mixing.
6. Mix the slurry for 30 minutes.

7. Take the pH of each slurry, beginning with the lime control, which will establish the initial soil pH.
8. Repeat the test twice more and average the pH achieved at each level of lime addition. Create a table of lime dose and pH (using the template shown in Table D-2).
9. Plot the data on a graph with the amount of lime addition to the soil slurry on the X-axis and the resulting average pH on the Y-axis (Figure D1).
10. A line drawn horizontally from the desired pH to the line formed from the experimental data and then dropped to the X-axis will provide an estimate of the amount of lime (per 20 grams of soil) that is needed to bring the soil to the desired pH.
11. This value is used in the calculation to determine tons of lime to be added to the soil for either a plowed-in treatment or a top-dressing treatment.

Table D-1. Procedure for lime addition to each experimental beaker.

Beaker	Lime (% soil weight)	Lime g
1	0.00	0.00
2	0.05	0.01
3	0.1	0.02
4	0.5	0.1
5	1.0	0.2
6	2.0	0.4
7	3.0	0.6
8	5.0	1.0

Table D-2. Soil slurry pH determined from each lime addition after mixing for 30 minutes.

Beaker	Lime (% soil weight)	Lime g	Soil pH			Avg pH
			Rep 1	Rep 2	Rep 3	
1	0.00	0.00				
2	0.05	0.01				
3	0.1	0.02				
4	0.5	0.1				
5	1.0	0.2				
6	2.0	0.4				
7	3.0	0.6				
8	5.0	1.0				

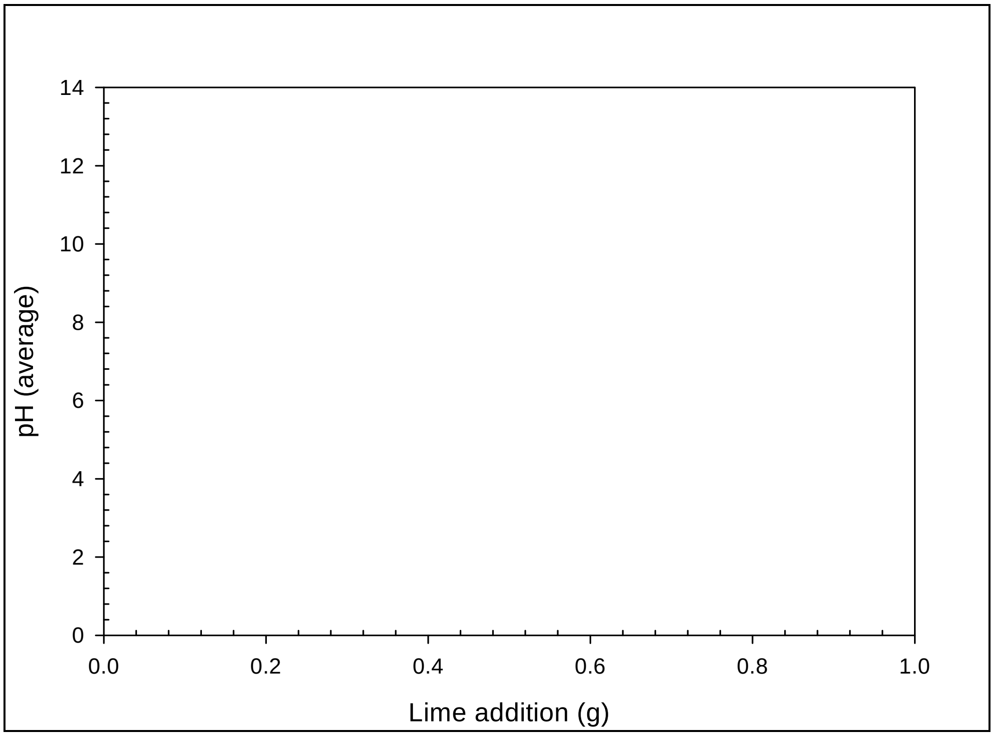

Figure D1. Graph of lime addition vs. average pH.

Calculation of lime dosage 6-inch application depth

- Uses – land in use
- Mode of application – mix into HGR soil
- Convert from grams of lime per 20 grams of soil to tons of lime per acre-6-inch.

(X g lime/20 g soil) x (153.8508) x 6 = Y tons lime/acre-6-in.

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Steven L. Larson, Jeffery L. Davis, W. Andy Martin, Deborah R. Felt, Catherine C. Nestler, Gene Fabian, Greg O'Connor, Greg Zynda, and Beth-Anee Johnson

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14. ABSTRACT

The Department of Defense operates hundreds of hand grenade ranges (HGR) for training purposes. Hand grenade training is a necessary function to maintain mission readiness for our nation's war fighters. Live fire training creates a potential source zone for munitions constituents such as metals and explosives. Fragmentation grenades, typically containing the high explosive composition B (60% RDX, 39%TNT) within a steel shell casing, constitute the majority of hand grenades used at fixed position ranges. Explosives have been detected in HGR soils at levels from the low parts per billion (µg/kg) up to percent levels. RDX has been detected in leachate waters below live fire HGRs and in surface waters leaving ranges. Two of the potential pathways for offsite migration of metals and explosives from HGR soil are transport in surface water and subsurface transport in leachate. Simple, innovative, and cost effective technologies are being developed which can break down munitions constituents quickly at the training sites and prevent residues from migrating to local surface water or groundwater supplies.

The application of hydrated lime to an HGR to provide a mechanism for both metals immobilization and explosives transformation was demonstrated at the Fort Jackson, SC HGRs. The results indicate that application of lime can reduce the munitions constituent migration by transforming energetic compounds by over 90%. In addition, the metals are stabilized in the soil, with reduction in the concentrations of iron and zinc leaving the range via surface water and leachate. This technology demonstrated that application of lime is a low-cost treatment that can be incorporated into range management operations and practices.

15. SUBJECT TERMS	Explosives	Metals	RDX
Alkaline hydrolysis	Field demonstration	Munitions	Sustainability
Composition B	Hand grenade	Range management	TNT

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U.S. Army Engineer Research and Development Center
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199;
U.S. Army Aberdeen Test Center
400 Colleran Road
Aberdeen Proving Ground, MD 21005;
Applied Research Associates, Inc.
119 Monument Place
Vicksburg, MS 39180;
ITAM-Shaw Environmental
Fort Jackson, SC 29207;
U.S. Army RDECOM-ARDEC
Energetics, Warheads, and Environmental Technology Research Division
Building 355
Picatinny, NJ 07806-5000